A Joint Report by the Nuclear Energy Agency and the International Atomic Energy Agency

Uranium 2022
Resources, Production and Demand




IAEA
International Atomic Energy Agency

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Uranium 2022:
Resources, Production and Demand

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Preface

Since the mid-1960s, with the co-operation of their member countries and states, the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) have jointly prepared periodic updates (currently every two years) on world uranium resources, production and demand. Such updates have been published in what are commonly known as the "Red Books".

This 29th edition features a comprehensive assessment of uranium supply and demand and projections through the year 2040. The basis of this assessment is a comparison of uranium resource estimates (according to categories of geological certainty and production cost) and mine production capability with anticipated uranium requirements arising from projected installed nuclear capacity. Current data on resources, exploration, production and uranium stocks are also presented, along with historical summaries of exploration and production, and plans for future mine development. Individual country reports offer detailed information on recent developments in uranium exploration and production, on environmental activities, regulatory requirements and on relevant national uranium policies.

This publication has been prepared on the basis of data obtained through questionnaires sent by the NEA to OECD member countries and by the IAEA to other countries. It contains official data provided by 36 countries and 18 national reports prepared by the secretariats of the NEA and the IAEA. This report is published under the responsibility of the OECD Secretary-General.

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Executive summary

Uranium 2022: Resources, Production and Demand presents the most recent review of world uranium market fundamentals and offers a statistical profile of the uranium industry. It contains 54 country reports on uranium exploration, resources, production and reactor-related requirements, 36 of which were prepared from officially reported government data and narratives, and 18 that were prepared by the secretariats of the Nuclear Energy Agency (NEA) and International Atomic Energy Agency (IAEA). The report includes projections for nuclear generating capacity and reactor-related uranium requirements through 2040, as well as a discussion of long-term uranium supply and demand issues.

The data reporting period for this edition of the so-called "Red Book" covers 1 January 2019 to 1 January 2021, although some relevant information for 2021 and 2022 is also included in the discussions.

Resources

Overall, global uranium resources decreased modestly in the reporting period, in contrast to the slight increases registered in previous recent editions of the "Red Book". Total identified recoverable resources decreased by nearly 2% from 2019, most notably in lower cost recoverable resources. The most significant decreases occurred in reasonably assured resources (<USD 40/kgU, -39%) and inferred resources (<USD 40/kgU, -5%). The decreases were primarily the result of mining depletion and cost category re-assignments of resources in Kazakhstan and Canada. Also contributing to decreases in these and other uranium producing countries were changes in cut-off grades, updated recoverability information, currency inflation effects and re-evaluations of previously identified uranium resources. This resulted in the decline of overall recoverable uranium, downgrades from reasonably assured resources to inferred resources and re-assignment of resources to higher or sub-economic cost categories.

Globally, Australia continues to lead with 28% of the world's identified recoverable resources (reasonably assured + inferred resources) in the category <USD 130/kgU (equivalent to USD 50/lb U_3O_8). Almost 80% of Australia's national total endowment is related to a single site, the Olympic Dam deposit. In terms of lower cost identified recoverable resources (<USD 80/kgU and <USD 40/kgU, equivalent to USD 30/lb U_3O_8 and USD 15/lb U_3O_8), Kazakhstan leads with 65% and 37% of the world total, respectively.

Australia reported increases in reasonably assured recoverable resources due to updated resource estimates at Olympic Dam, but decreases in inferred recoverable resources, while Kazakhstan reported overall decreases in reasonably assured resources as a result of mining depletion and transfer of high-cost resources to the sub-economic category. Noteworthy changes in resources also occurred in other countries, such as Canada, Central African Republic, Mongolia, Namibia and Niger. Canada experienced a significant decrease in lowest cost category reasonably assured recoverable resources (<USD 40/kgU) due to the combined effects of inflation, changes in cut-off grades and mining depletion. In other countries, the re-estimation of resources resulted in adjustments in resource values, such as shifting of resources from lower to higher cost categories and from inferred to reasonably assured resources.

Global identified recoverable resources of uranium, expressed in tonnes of uranium metal (tU), in the <USD 130/kgU category as of 1 January 2021 amounted to 6 078 500 tU, a decrease of just over 1% compared to 2019. In the highest cost category (<USD 260/kgU, equivalent to USD 100/lb U_3O_8), total identified resources amounted to 7 917 500 tU, a decrease of nearly 2% compared to the total reported for the previous edition.

Reasonably assured resources decreased most notably in the lowest cost category (<USD 40/kgU), by nearly 39% compared to the amounts reported in 2019. Small decreases also occurred in the <USD 80/kgU and <USD 260/kgU cost categories (2.6% and 0.7%, respectively), with a slight increase of 0.6% in the <USD 130/kgU category.

Inferred resources in the <USD 260/kgU cost category decreased overall by 3.5% from 3 346 400 tU in 2019 to 3 229 200 tU in 2021, mainly due to the re-evaluation of resources and conversion of inferred to reasonably assured resources as a result of exploration activities. Australia and Kazakhstan reported the most significant decreases, while Mongolia and Niger reported some increase in inferred resources.

Although all resources in this publication are reported as recoverable, a summary has also been prepared for *in situ* identified resources worldwide. The recovery factor from in situ to recoverable resources is 74% overall, but increases to 83% when only resources in the low cost <USD 40/kgU category are considered. Compared with the previous edition, the total identified in situ resources increased slightly from 10 584 500 tU to 10 671 800 tU. Reporting *in situ* resources provides a more optimistic view of the available resource base and gives some indication of how the resource base could increase with improvements in mining and processing methods, which would lead to better recovery.

Additions to the conventional resource base in the future could come from undiscovered resources (prognosticated resources and speculative resources), which as of 1 January 2021 amounted to 7 365 500 tU, a 2% increase from the 7 220 300 tU reported in the previous edition. Unconventional resources are another source of potential future supply, and currently amount to nearly 39 million tU. It is important to note that in some cases, including several major producing countries with large identified resource inventories, estimates of undiscovered resources and unconventional resources are either not reported or have not been updated for several years.

The uranium resource figures presented in this volume are a snapshot of the situation as of 1 January 2021, as reported mainly from official government sources. Readers should keep in mind that resource figures are dynamic and related to commodity prices.

Exploration and mining development

Continuing a downward trend over several years, worldwide domestic exploration and mine development expenditures decreased to approximately USD 250 million in 2020 from nearly USD 500 million in 2018 and over USD 2 billion in 2014 (note that expenditures made by junior exploration companies in some significant producing countries was unavailable). Preliminary data for 2021 expenditures suggest a minor increase to nearly USD 280 million. Non-domestic figures, a subset of global exploration and development expenditures, declined significantly from nearly USD 420 million in 2016 to under USD 40 million in 2020, with a minor increase to just over USD 70 million expected in 2021 (preliminary data). Total expenditures continue to decrease in response to a depression in the uranium market that has lasted since mid-2011.

From 2014, total domestic expenditures dropped from over USD 2 billion to USD 876.5 million in 2015, USD 681.9 million in 2016, USD 482.9 million in 2018 and USD 251.3 million in 2020. In 2020, global expenditures on exploration and mine development were down 88% from 2014. However, global expenditures increased by 10% in 2021 from 2020 (preliminary data). Expenditures decreased in many countries, mainly because of persistently depressed uranium prices, which slowed or delayed several exploration and mine development projects. Another reason is the significant spending on the construction of the Husab mine in Namibia which was completed in 2017 after a three year project.

Total exploration and mine development expenditures from 2018 through 2020 in the reporting countries amounted to USD 1.25 billion, with Canada, China, India, Russia and Kazakhstan leading the way. Expenditures in Canada alone exceeded the total spending of the remaining top five countries and amounted to 44% of the total.

From 2018 to 2020, the total estimated overall length of global exploration and development drilling decreased by almost 50%, from 2 633 km to 1 363 km. Kazakhstan accounted over 58% of the total exploration and development drilling length reported in 2020, with India, Türkiye, Russia, Namibia and Ukraine accounting for most of the remainder. Part of this significant overall decrease may be explained by the absence of drilling data from Canada and China for 2020.

Production

Global uranium mine production decreased by nearly 12% from 2018 to 2020. Major producing countries, including Canada and Kazakhstan, limited total production in recent years in response to a depressed uranium market. Uranium production cuts deepened suddenly with the onset of the COVID-19 pandemic in early 2020. As of 1 January 2021, the annual production capacity of idled mines amounted to over 29 400 tU. These operations, which have all the necessary licenses, permits and agreements for operation and have produced commercially in the past, could potentially be brought back into production relatively rapidly given appropriate market conditions.

In 2020, 16 countries produced uranium for a global total of 47 432 tU. Kazakhstan's continuous growth in production reached a peak of 24 689 tU in 2016, after which it started to decline in 2017 as production cuts were instituted to reduce supply to an oversupplied market. Kazakhstan nonetheless remained by far the world's largest producer, even as production was eased back from 21 705 tU in 2018 to 19 477 tU in 2020. Kazakhstan's 2020 production alone totalled more than the combined production in that year from Australia, Namibia, Canada, and Uzbekistan, respectively the second, third, fourth and fifth largest producers of uranium in 2020. These five countries accounted for 81% of global uranium output that year.

In situ leaching (ISL) remained the dominant production technology throughout the reporting period, accounting for over 58% of total global uranium production in 2020 and approximately 63% in 2021.

Overall, world uranium production decreased by 12% from 53 501 tU in 2018 to 47 342 tU in 2020 as producers instituted production cuts, followed by a slight increase to 47 472 tU in 2021. These planned reductions were greatest in Canada and Kazakhstan. In Canada, for example, uranium production was reduced by 45% from 6 996 tU in 2018 to 3 878 tU in 2020. Mining at Rabbit Lake was suspended in mid-2016, while mining at the McArthur River and milling at Key Lake were suspended at the end of January 2018, all due to unfavourable market conditions. Production also declined dramatically in the United States. These actions are in addition to a list of 14 idled mines (defined as mines with associated identified uranium resources and mining/processing facilities that have all the necessary licenses, permits and agreements for operation and have produced commercially in the past). As of 1 January 2021, the annual production capacity of idled mines amounted to over 29 400 tU. It should be noted, however, that idled mines could be brought back into production relatively rapidly with appropriate market signals.

Planned uranium production cuts were further deepened with the onset of the COVID-19 pandemic in early 2020. In Canada, in March 2020, Cameco announced that it had suspended production at the Cigar Lake mine and Orano announced that it had suspended work at the McClean Lake mill in response to the COVID-19 pandemic. In Kazakhstan, in early April 2020, JSC National Atomic Company Kazatomprom announced that it was reducing operational activities at all uranium mines for three months due to the COVID-19 pandemic. The pandemic also caused restrictions at other mining operations, such as in Australia, Namibia and South Africa. In August 2020, some of these restrictions were eased and several producers gradually resumed production. However, with these unplanned reductions, some producers did not reach their 2020 production targets.

Environmental and social aspects of uranium exploration and production

With uranium production projected to expand to meet global demand over the medium-term, efforts are being made to develop safe mining practices and to continue to minimise environmental impacts. The country reports provide some updates about the environmental and social aspects of uranium mining, including site remediation and decommissioning projects, which highlight the progress that the uranium industry has made on environmental stewardship.

Although the focus of this publication remains uranium resources, production and demand, the environmental and social aspects of the uranium production cycle are gaining in importance and, as in the last few editions, updates on activities in this area have been included in the country reports. With a need for increased uranium production to meet demand, the continued development of transparent, safe and well-regulated operations that minimise environmental impacts is crucial, particularly for those countries hosting uranium production for the first time.

For this edition, 26 countries provided information on activities related to the environmental aspects of the uranium production cycle, including ongoing work related to closed facilities and policy/regulatory-related issues.

Additional information on the environmental aspects of uranium production may be found in *Managing Environmental and Health Impacts of Uranium Mining* (NEA, 2014[1]), which outlines the significant improvements made in these areas since the early strategic period of uranium mining. The IAEA Bulletin, *Uranium: From Exploration to Remediation* (IAEA, 2018[2]) includes some information on this topic. More recently, the NEA published a comprehensive overview of the experiences in the uranium mining industry of working with Indigenous people and local communities to maximise overall benefits for all stakeholders in *Maximising Uranium Mining's Social and Economic Benefits: A Guide for Stakeholders* (NEA, 2023[3]).

Uranium demand

World nuclear capacity is expected to rise for the foreseeable future as global energy demand is projected to increase and the need for a clean energy transition grows. Reactor-related uranium requirements vary considerably from region to region, reflecting projected nuclear capacity increases and possible inventory building. Annual uranium requirements are projected to be largest in the East Asia region by 2040. Recognising the security of supply, reliability and predictability that nuclear power offers and promoting incentives for all types of low-carbon technologies are key conditions for greater growth in nuclear capacity, and consequently, in uranium demand.

As of 1 January 2021, a total of 442 commercial nuclear reactors were connected to the grid globally, with a net generating capacity of 393 GWe requiring about 60 100 tU annually (about 150 tU per GWe of electrical generating capacity for an already-operating reactor). Taking into account changes in policies announced in several countries and revised nuclear programmes as of 1 January 2021, world nuclear capacity by 2040 is projected to remain at the current level of 394 GW in the low demand case but increase to 677 GW in the high demand case (an increase of around 70%, with respect to 2020 capacity). Accordingly, world annual reactor-related uranium requirements (excluding the use of mixed oxide fuels, which is marginal) are projected to rise to between 63 000 tU/y and 108 200 tU/y by 2040.

1. NEA (2014), *Managing Environmental and Health Impacts of Uranium Mining*, OECD Publishing, Paris, https://oecd-nea.org/jcms/pl_14766/managing-environmental-and-health-impacts-of-uranium-mining.
2. IAEA (2018), *Uranium: From Exploration to Remediation*, IAEA Bulletin, Volume 59-2, June 2018, Vienna, www.iaea.org/bulletin/59-2.
3. NEA (2023), *Maximising Uranium Mining's Social and Economic Benefits: A Guide for Stakeholders*, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_72776/maximising-uranium-mining-s-social-and-economic-benefits-a-guide-for-stakeholders.

Nuclear energy capacity projections vary considerably from region to region. East Asia is projected to experience the largest increase of generating capacity in absolute terms, which, by the year 2040, could result in increases of between 35 GW and 152 GW over 2020 capacity, corresponding to 130% and 240% increases in the low and high cases, respectively. While representing a significant regional capacity increase, it is important to note that countries of this region (e.g. China) have in recent years demonstrated the ability to build multiple reactors with predictable costs and schedules.

Other regions projected to experience significant nuclear capacity growth by 2040 include the Middle East, Central and Southern Asia. For these regions collectively, the low and high cases project an additional growth of between 27 GW and 51 GW with respect to 2020 capacity.

In Europe, nuclear capacity in non-EU member countries is projected to increase in the high case scenario to 93 GW by 2040. On the basis of 2021 data, in the European Union, nuclear capacity in 2040 is projected to decrease by 25% in the low case scenario and increase only by 16% in the high case with respect to 2020 capacity.

Modest growth in terms of absolute capacity increase is projected in Africa, Central and South America and South-eastern Asia.

For North America, the projections see nuclear generating capacity decreasing by 2040 in the low case (-42%) and roughly flat in the high case (+3%), with respect to 2020 capacity. These projections depend largely on future electricity demand, lifetime extensions of existing reactors, government policies with respect to greenhouse gas emissions and investment in new nuclear power capacity.

As in the case of nuclear capacity, uranium requirements vary considerably from region to region, reflecting projected capacity increases and possible inventory building. By 2040, annual uranium requirements are projected to be largest in the East Asia region, where an increase in installed nuclear generating capacity drives significant growth in uranium needs.

Key factors influencing future nuclear energy capacity include projected electricity demand, the economic competitiveness of nuclear power plants, associated financing arrangements for such capital-intensive projects, proposed waste management strategies and public acceptance of nuclear energy and national energy security strategies. The extent to which nuclear energy is seen to be beneficial in climate change mitigation and in securing greater energy independence in light of recent geopolitical events will be key to unlocking even greater projected growth in nuclear capacity and, consequently, in uranium demand.

The importance of energy security was highlighted by the COVID-19 pandemic in 2020 and 2021 and even more so in 2022 by the war in Ukraine and the ensuing energy security crisis in Europe. Realising the full contribution of nuclear power to climate change mitigation and to energy security requires recognising the reliability and predictability that nuclear power offers and providing appropriate incentives for all types of low-carbon technologies, in particular new builds of both conventional large reactors and small modular reactors. In the near term, extensions to the operating timeframes of existing nuclear power plants are also required. Already in 2021 and 2022, many governments (including France, Japan and Korea) changed their policies in favour of developing nuclear energy sources, both conventional and advanced new reactors. It can be anticipated that these policy shifts will impact the projections in future editions of the Red Book.

Supply and demand relationship

The currently defined resource base is more than adequate to meet even high case uranium demand through 2040, but doing so will depend upon timely investments to turn resources into production. At the end of the reporting period, meeting high case demand requirements to 2040 would consume about 80% of the total 2020 identified recoverable resource base at a cost of <USD 30/lb U_3O_8 (USD 80/kgU). In light of more recent market prices sustained through the end of 2022, meeting high case growth requirements to 2040 would consume about 26% of identified recoverable resources available at a cost of <USD 50/lb U_3O_8 (USD 130/kgU).

As of 1 January 2021, world uranium production covered nearly 79% of world reactor requirements, down from about 86% in 2019, with the remainder supplied by secondary sources. Such secondary supply includes excess government and commercial inventories, spent fuel reprocessing, underfeeding and uranium produced by the re-enrichment of depleted uranium tails, as well as low-enriched uranium produced by blending down highly enriched uranium.

During the past decade, the decline in uranium market prices after the 2011 Fukushima Daiichi accident and the uncertainty about nuclear power development in some countries reduced uranium requirements, further depressed prices and slowed the pace of mine production and development. More recently, the increase in uranium spot prices (at the end of 2022 to around USD 50/lb U_3O_8 or USD 130/kgU), can be explained by the additional curtailments to primary production brought on by the COVID-19 pandemic in 2020 and 2021 and the uncertainties related to the shifting geopolitical situation in 2022. It is worth noting, however, that the reduction in uranium mining and ore processing activities due to the pandemic did not disrupt the performance of nuclear power reactors, as utilities and fuel cycle producers hold significant inventories.

Meeting high case growth requirements to 2040 would consume about 26% of identified recoverable resources available at a cost of <USD 130/kgU and about 20% of these at a cost of <USD 260/kgU. However, when considering lower cost resources, in light of 2020 and 2021 market prices, at a cost of less than USD 80/kgU, in the high demand case meeting projected requirements to 2040 would consume about 80% of identified recoverable resources.

For the foreseeable future, projected primary uranium production capabilities, including existing, committed, planned and prospective production centres, would satisfy projected low-case requirements through 2040, and partially satisfy high-case requirements, if new mining developments proceed as planned.

For this to happen, however, significant investment and technical expertise will be required to bring these resources to the market. Producers will have to overcome a number of significant, and at times unpredictable, issues in bringing new production facilities on stream, including geopolitical and local factors, technical challenges and complex legal and regulatory frameworks. Strong market conditions will be critical to achieve the required industry investment.

Although low market prices have led to significant reductions in uranium production and a delay in some mine development projects in recent years, other projects have advanced through further stages of development. An improvement of uranium market conditions should also see some of the delayed projects or idled mines reactivated in order to ensure supply to a growing global nuclear fleet. The current global network of uranium mine facilities is relatively sparse, creating the potential for supply vulnerabilities. However, utilities have been building significant inventory over the last few years at reduced prices, which should help to protect them from such events in the near term.

Although information on secondary sources is incomplete, the availability of these sources is generally expected to decline somewhat in the 2020s. Existing information, however, indicates that there remains a significant amount of previously mined uranium, some of which could possibly be brought to the market in the coming years. With the enrichment capacity temporarily in excess of requirements, enrichment providers are well-positioned to reduce tails assays below contractual requirements and thereby create additional uranium supply. In the longer term, alternative fuel cycles, if successfully developed and implemented and, in particular, closing the fuel cycle, could have a very significant impact on the uranium market. It is too early to say how cost-effective and widely implemented these proposed alternative fuel cycles could be.

Conclusions

Sufficient uranium resources exist to support continued use of nuclear power and significant growth in nuclear capacity for electricity generation and other uses (e.g. heat, water, hydrogen) in the near to long term. Identified recoverable resources, which include reasonably assured and inferred resources combined, at a cost category of <USD 260/kgU (equivalent to USD 100/lb U_3O_8),

are sufficient for more than 130 years, considering the uranium requirements of the year 2020. At the end of the reporting period for this edition of the “Red Book”, when early 2021 uranium market prices were about USD 30/lb U_3O_8 (USD 78/kg U), only 25% of the recoverable resource base outlined in this edition of the “Red Book” could be economically brought into production, since resources with estimated mining costs greater than 80 USD/kgU cannot be profitably mined at such prices. Hence, given those market and economic conditions, identified recoverable resources at a cost category of <USD 80/kgU (equivalent to USD 30/lb U_3O_8, the average price of uranium in early 2021) would be sufficient for only about 30 years of global reactor-related uranium requirements, considering 2020 uranium requirement figures. At average market prices of about USD 50/lb U_3O_8 (USD 130/kg U), beginning in mid-2021 and sustained through the beginning of 2023, approximately 75% of the recoverable resource base could be economically brought into production, representing about 100 years of uranium requirements. Favourable prices would need to be sustained – and significant timely investment and technical expertise will be required – to turn these resources into refined uranium ready for nuclear fuel production.

Global uranium demand is expected to continue to increase in the next several decades to meet large population needs, particularly in emerging economies. Since nuclear energy produces competitively priced, low-carbon baseload electricity and enhances the security of energy supply, it is projected to remain an important component in the mix of low carbon energy supply.

The abundance of low-cost natural gas in North America and the risk-averse investment climate have reduced the competitiveness of nuclear power plants in some liberalised electricity markets. Government and market policies that recognise the benefits of low-carbon electricity production and the security of energy supplied by nuclear power plants could help alleviate these competitive pressures.

In 2021 and 2022, the perception of nuclear energy as a strategic resource for energy independence has started to change in many countries, as reflected by recent government nuclear energy policy changes. Noting that this was also due to the dramatic European energy crisis of 2022 brought by the shifting geopolitical situation, the 2024 edition of the “Red Book” will aim to provide a fuller picture of the implications of these developments on uranium demand and supply.

After a period of reductions in uranium production, slowed investment and comparatively low prices, it remains to be seen whether the quickly evolving market and policy environment will provide incentives for the uranium market to expand substantially in the coming decades.

Chapter 1. **Uranium supply**

This chapter summarises the status of worldwide uranium resources, exploration and production. The data reporting period for this edition of the Red Book covers 1 January 2019 to 1 January 2021 (i.e. the calendar years 2019 and 2020). However, some important information for 2021 and 2022 has also been included when needed.

Uranium resources

Uranium resources are classified by a scheme (based on geological certainty and costs of production) developed to combine resource estimates from a number of different countries into harmonised global figures. ***Identified resources*** (which include ***reasonably assured resources****,* or *RAR,* and ***inferred resources***, or *IR*) refer to uranium deposits delineated by sufficient direct measurement to conduct pre-feasibility and sometimes feasibility studies. For ***reasonably assured resources***, high confidence in estimates of grade and tonnage are generally compatible with mining decision-making standards. ***Inferred resources*** are not defined with such a high degree of confidence and generally require further direct measurement prior to making a decision to mine. ***Undiscovered resources*** (which include ***prognosticated resources****,* or *PR*, and ***speculative resources****,* or *SR*) refer to resources that are expected to exist based on geological knowledge of previously discovered deposits and regional geological mapping. ***Prognosticated resources*** refer to those expected to exist in known uranium provinces, generally supported by some direct evidence. ***Speculative resources*** refer to those expected to exist in geological provinces that may host uranium deposits. Both ***prognosticated*** and ***speculative resources*** require significant amounts of exploration before their existence can be confirmed and grades and tonnages can be defined. ***Unconventional resources*** are defined as very low-grade resources or those from which uranium is only recoverable as a minor by-product or co-product. For a more detailed description, see Appendix 3.

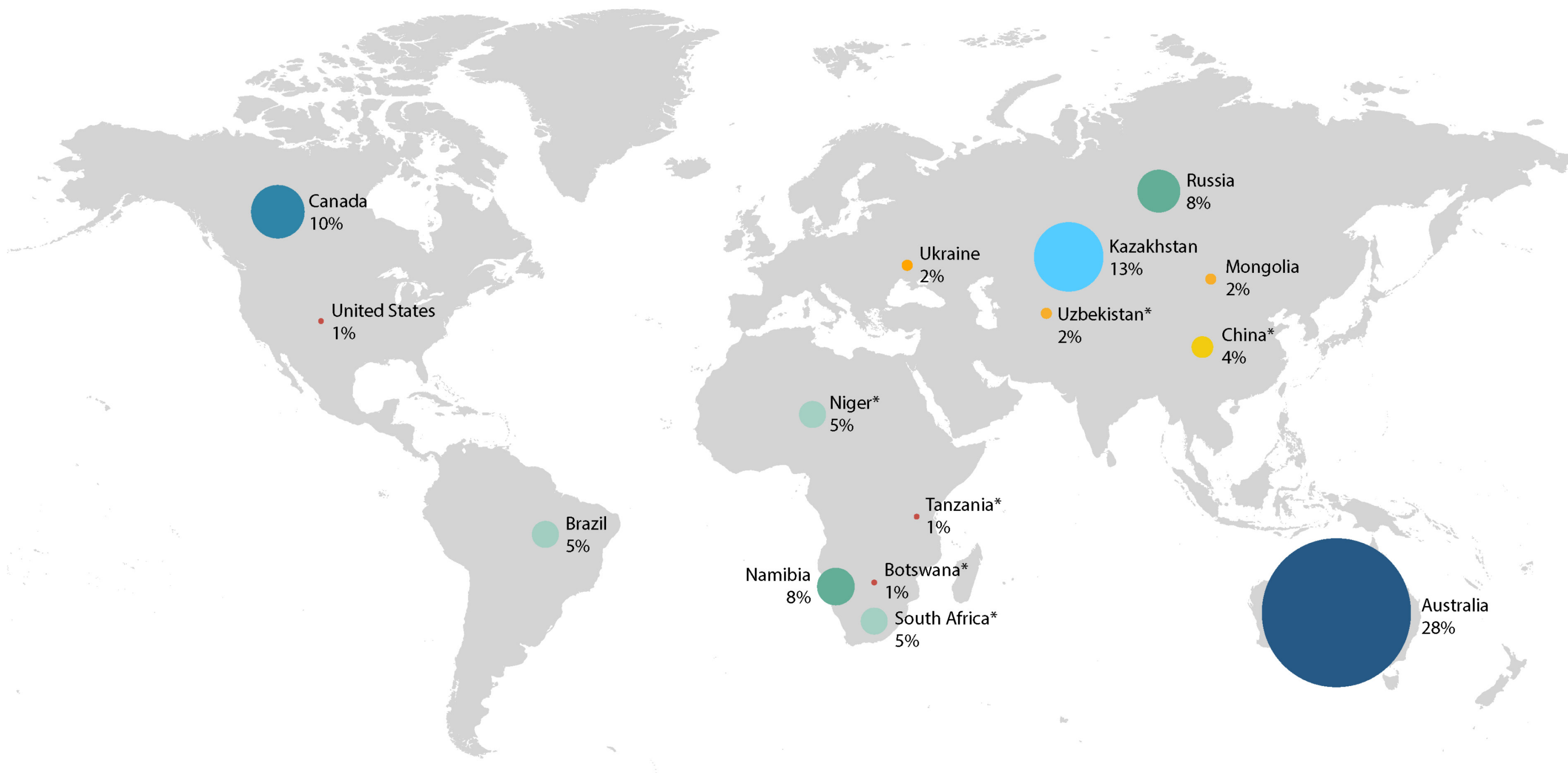
Identified conventional resources

The global distribution of identified conventional resources, recoverable at a cost of less than USD 130/kgU is shown in Figure 1.1. Identified resources consist of *reasonably assured resources* (RAR) and *inferred resources* (IR) recoverable at a cost of less than USD 260/kgU (USD 100/lb U_3O_8; see Appendix 3). Unless otherwise noted, resource figures in this report refer exclusively to recoverable resources; that is, the potential amount of uranium recovered after losses from mining and processing are deducted. In situ resources are also presented at times in this report, referring to the estimated amount of uranium in the ground, and are clearly indicated as such (see Appendix 3).

Relative changes in different resource and cost categories of global identified resources between this edition and the 2020 edition of the Red Book are summarised in Table 1.1 (note that resources of a given cost category also include resources from lower cost categories, in other words, the resource amounts are cumulative from lowest to highest cost category; see Appendix 3 about how to read and interpret cost category resource figures).

Figure 1.1. **Global distribution of identified recoverable conventional uranium resources**

(<USD 130/kgU as of 1 January 2021)



* Secretariat estimate or partial estimate.

The global distribution of identified recoverable conventional uranium resources in the <USD 130/kgU cost category among 15 countries, which are either major uranium producers or have significant plans for growth of nuclear generating capacity, illustrates the widespread distribution of these resources. Together, these 15 countries are endowed with 95% of the global resource base as specified above (the remaining 5% are distributed among another 24 countries). The widespread distribution of uranium resources is an important geographic aspect of nuclear energy in light of security of energy supply.

Table 1.1. **Changes in identified resources (recoverable) 2019-2021**
(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes*)

Resource category	2019	2021	Change[(a)]	% change
Identified (total)				
<USD 260/kgU	8 070 400	7 917 500	-152 900	-1.9
<USD 130/kgU	6 147 800	6 078 500	-69 300	-1.1
<USD 80/kgU	2 007 600	1 990 800	-16 800	-0.8
<USD 40/kgU[(b)]	1 080 500	775 900	-304 600	-28.2
RAR				
<USD 260/kgU	4 723 700	4 688 300	-35 400	-0.7
<USD 130/kgU	3 791 700	3 814 500	22 800	0.6
<USD 80/kgU	1 243 900	1 211 300	-32 600	-2.6
<USD 40/kgU[(b)]	744 500	457 200	-287 300	-38.6
Inferred resources				
<USD 260/kgU	3 346 400	3 229 200	-117 200	-3.5
<USD 130/kgU	2 355 700	2 263 900	-91 800	-3.9
<USD 80/kgU	763 600	779 600	16 000	2.1
<USD 40/kgU[(b)]	335 900	318 700	-17 200	-5.1

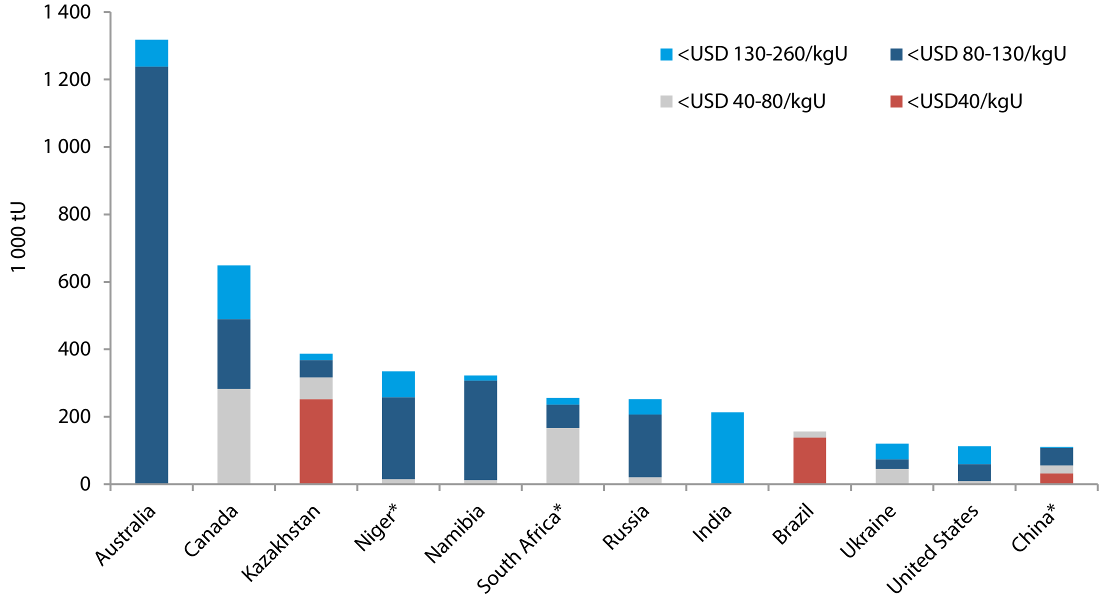
* Note that tonnes U values in this table are rounded to the nearest 100 tonnes, independently, at the country and cost range level. Therefore, these cost range totals do not exactly match totals for these cost ranges as shown in other tables relating to uranium resources in this report. (a) Changes might not equal differences between 2019 and 2021 because of independent rounding. (b) Resources in the cost category of <USD 40/kgU and <USD 80/kgU should be regarded with some caution since some countries do not report low-cost resource estimates, mainly for confidentiality concerns, whereas other countries that have never, or not recently, hosted uranium mining may be underestimating mining costs.

Contrary to recent editions, the overall picture from 1 January 2019 to 1 January 2021 is one of decreasing global identified conventional uranium resources with the decrease in recoverable resources greatest (-28%; >304 000 tU) in the lowest cost category (<USD 40/kgU). Decreases in identified conventional resources occurred in all higher cost categories as well but were much less pronounced (<2%). Highest cost (<USD 260/kgU) identified recoverable resources totalled over 7.9 million tU a decline of 1.9% from 2019. Low-cost (<USD 40/kgU) RAR declined most dramatically (-39%; 287 000 tU) and higher cost RAR followed a similar pattern to total identified resources, with declines in each cost category amounting to <3%. IR declined less dramatically overall (-5%) except for the <USD 80kgU cost category which increased modestly by 2.1% (16 000 tU).

The overall decrease in the lowest cost category (<USD 40/kgU) of identified conventional resources is principally the result of the removal of over 250 000 tU from the lowest cost category in Canada (the country no longer reports in this category), along with mining depletion in Canada, Kazakhstan and Uzbekistan. As of 1 January 2021, only Argentina (2 400 tU), Brazil (138 100 tU), China (73 200 tU), Kazakhstan (502 000 tU), Spain (8 100 tU) and Uzbekistan (52 100 tU) reported recoverable uranium resources in the lowest cost category (<USD 40/kgU). Much less dramatic declines (-2% or less) of identified resources in the higher cost (<USD 80/kgU, <USD 130/kgU and <USD 260/kgU), were principally the result of mining depletion in Russia and Ukraine, the removal of over 100 000 tU of high-cost resources in Kazakhstan (Kosachinoye field open-pit and underground resources), downgrading of Bakouma resources in the Central African Republic, the movement of lower cost (<USD 80/kgU) resources in Mongolia to higher cost categories and reductions due to the reassessment of recoverability factors in China and Türkiye. This was balanced by increases in Guyana, Hungary, India, Malawi, Mauritania, Mongolia, Namibia, Niger and, to a lesser extent Paraguay, as a result of a combination of new discoveries and ongoing exploration activities, supplemented by the movement of resources into higher cost categories in Canada and the United States.

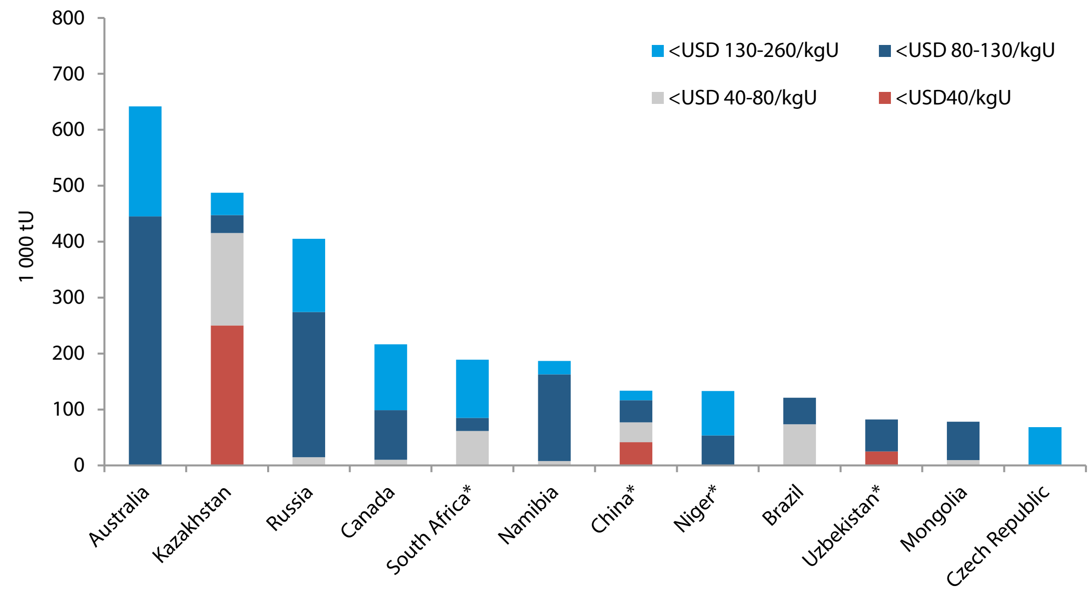
Current estimates of identified resources, RAR and IR, on a country-by-country basis, are presented in Tables 1.2, 1.3 and 1.4 and graphically summarised in Figures 1.2 and 1.3. Table 1.5 summarises major changes in resources between 2019 and 2021 in selected countries.

Figure 1.2. **Distribution of reasonably assured recoverable conventional uranium resources among select countries with a significant share of resources**



* Secretariat estimate or partial estimate.

Figure 1.3. **Distribution of inferred recoverable conventional uranium resources among select countries with a significant share of resources**



* Secretariat estimate or partial estimate.

Table 1.2a. **Identified recoverable resources**

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Algeria[a,b]	0	0	0	19 500
Argentina	2 400	19 300	34 300	35 300
Australia	NA	NA	1 684 100	1 959 800
Bolivia[a,b]	0	0	0	1 400
Botswana*	0	0	87 200	87 200
Brazil[b]	138 100	229 400	276 800	276 800
Canada	0	292 400	588 500	865 400
Central African Republic*[b]	0	0	0	29 200
Chad*[a,b,c,d]	0	0	0	2 400
Chile*[a,b,c]	0	0	0	1 400
China*[b,c,e]	73 200	132 500	223 900	244 700
Congo, Dem. Rep.*[a,b,c]	0	0	0	2 700
Czech Republic	0	0	800	119 100
Denmark/Greenland[b]	0	0	0	114 000
Egypt[b]	0	0	400	1 900
Finland[a,b]	0	0	1 200	1 200
Gabon[a,c]	0	0	4 800	5 800
Germany[a]	0	0	0	7 000
Greece[a,c]	0	0	0	7 000
Guyana[a,b]	0	0	0	4 600
Hungary[b]	0	0	0	16 700
India[b,d]	NA	NA	NA	220 900
Indonesia[d,f]	0	1 500	8 600	8 600
Iran, Islamic Republic of*[b,c]	0	0	7 400	7 400
Italy[a,c]	0	6 100	6 100	6 100
Japan[a]	0	0	6 600	6 600
Jordan[b]	0	0	52 500	52 500
Kazakhstan[b]	502 000	732 100	815 200	874 700
Malawi*	0	0	9 500	16 300
Mali*[b]	0	0	8 900	8 900
Mauritania*	0	0	18 800	26 100
Mexico[b]	0	0	3 700	5 000
Mongolia[g]	0	16 900	144 600	144 600
Namibia	0	19 700	470 100	509 500
Niger*	0	14 600	311 100	468 000
Paraguay*[b]	0	0	4 400	4 400
Peru*[b]	0	33 400	33 400	33 400
Portugal[a,b,g]	0	3 600	5 600	5 600
Romania*[a,c]	0	0	6 600	6 600
Russia[f]	0	35 000	480 900	656 900
Senegal*[b]	0	0	0	1 100
Slovak Republic[a,b]	0	12 700	15 500	15 500

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Table 1.2a. **Identified recoverable resources** *(cont'd)*

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Slovenia(a,b)	0	5 400	9 200	9 200
Somalia*(a,b,c)	0	0	0	7 600
South Africa*	0	228 000	320 900	444 700
Spain(b)	8 100	28 500	28 500	28 500
Sweden*(a,b)	0	0	9 600	9 600
Tanzania*(f)	0	46 800	58 200	58 200
Türkiye(b,f,g)	0	0	11 700	12 700
Ukraine	0	71 800	107 200	185 400
United States(b)	0	9 000	59 400	112 200
Uzbekistan*	52 100	52 100	131 300	131 300
Viet Nam*(a,b)	0	0	0	3 900
Zambia*	0	0	31 000	31 000
Zimbabwe(a,b,c)	0	0	0	1 400
Total(h)	775 900	1 990 800	6 078 500	7 917 500

* Secretariat estimate. ** Note that tonnes U values in this table are rounded to the nearest 100 tonnes, independently, at the country and cost range level. Therefore, these cost range totals do not exactly match totals for these cost ranges as shown in other tables relating to uranium resources in this report. (a) Assessment not made within the last five years. (b) In situ resources were adjusted by the Secretariat to estimate recoverable resources using recovery factors provided by countries or estimated by the Secretariat. (c) Not reported in 2021 responses, data from previous Red Book. (d) Cost data not provided, therefore resources are reported in the <USD 260/kgU category. (e) Updated recovery factors. (f) Assessment partially made within the last five years. (g) Updated to report recoverable resources. (h) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for confidentiality concerns, whereas other countries that have never, or not recently, hosted uranium mining, may be underestimating mining costs.

Table 1.2b. **Identified in situ resources**

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Algeria(a)	0	0	0	26 000
Argentina(b)	3 200	25 800	46 100	47 500
Australia(b)	NA	NA	2 608 400	3 061 400
Bolivia(a)	0	0	0	1 700
Botswana*(b)	0	0	140 600	140 600
Brazil	184 300	314 600	382 300	382 300
Canada(b)	0	304 600	638 400	992 300
Central African Republic*	0	0	0	36 500
Chad*(a,c,d)	0	0	0	3 200
Chile*(a,c)	0	0	0	1 900
China*(c)	104 600	188 100	311 800	339 500
Congo, Dem. Rep.*(a,c)	0	0	0	3 600
Czech Republic(b)	0	0	1 300	197 300
Denmark/Greenland	0	0	0	228 000
Egypt	0	0	500	2 500
Finland(a)	0	0	1 500	1 500
Gabon(a,b,c)	0	0	6 400	7 700

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Table 1.2b. **Identified in situ resources** *(cont'd)*

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Germany[a,b]	0	0	0	9 300
Greece[a,b,c]	0	0	0	9 300
Guyana[a]	0	0	0	6 200
Hungary	0	0	0	22 200
India[d]	NA	NA	NA	292 900
Indonesia[e]	0	2 000	11 500	11 500
Iran, Islamic Republic of*[c]	0	0	9 900	9 900
Italy[a,b,c]	0	8 100	8 100	8 100
Japan[a,b]	0	0	7 800	7 800
Jordan	0	0	70 000	70 000
Kazakhstan	564 000	823 100	919 300	991 000
Malawi*[b,f]	0	0	11 800	21 300
Mali*	0	0	11 800	11 800
Mauritania*[b]	0	0	21 800	31 600
Mexico	0	0	4 900	6 700
Mongolia[b]	0	22 500	192 200	192 200
Namibia[b]	0	24 600	587 600	636 900
Niger*[b,f]	0	18 000	384 100	586 000
Paraguay*	0	0	5 100	5 100
Peru*	0	47 700	47 700	47 700
Portugal[a]	0	4 500	7 000	7 000
Romania*[a,b,c]	0	0	8 800	8 800
Russia[b,e]	0	46 600	590 200	840 900
Senegal*	0	0	0	1 500
Slovak Republic[a]	0	15 800	19 300	19 300
Slovenia[a]	0	7 200	12 200	12 200
Somalia*[a,c]	0	0	0	10 200
South Africa*[b]	0	311 600	436 900	612 000
Spain	9 800	34 400	34 400	34 400
Sweden*[a]	0	0	12 800	12 800
Tanzania*[b,e]	0	58 500	72 800	72 800
Türkiye[e]	0	0	15 300	16 700
Ukraine[b]	0	82 000	121 900	211 100
United States	0	12 000	79 200	149 500
Uzbekistan*[b]	65 200	65 200	170 300	170 300
Viet Nam*[a]	0	0	0	5 200
Zambia*[b]	0	0	34 300	34 300
Zimbabwe[a,c]	0	0	0	1 800
Total[g]	931 100	2 416 900	8 046 300	10 671 800

* Secretariat estimate. ** Note that tonnes U values in this table are rounded to the nearest 100 tonnes, independently, at the country and cost range level. Therefore, these cost range totals do not exactly match totals for these cost ranges as shown in other tables relating to uranium resources in this report. (a) Assessment not made within the last five years. (b) Recoverable resources were adjusted by the Secretariat to estimate in situ resources using recovery factors provided by countries or estimated by the Secretariat according to the expected production method (Appendix 3). (c) Not reported in 2021 responses, data from previous Red Book. (d) Cost data not provided, therefore resources are reported in the <USD 260/kgU category. (e) Assessment partially made within the last five years. (f) Updated recovery factors. (g) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for reasons of confidentiality, whereas other countries that have never, or not recently, hosted uranium mining, may be underestimating mining costs.

Table 1.2c. **Comparison of identified resources reported as in situ versus recoverable**

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Identified resources (tU)	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Total in situ	931 100	2 416 900	8 046 300	10 671 800
Total recoverable	775 900	1 990 800	6 078 500	7 917 500
Difference	155 200	426 100	1 967 800	2 754 300
Difference %	16.7	17.6	24.5	25.8
Recovery %	83.3	82.4	75.5	74.2

(as of 1 January 2019, tonnes U; Red Book 2020)

Identified resources (tU)	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Total in situ	1 268 400	2 456 300	8 070 300	10 584 500
Total recoverable	1 080 500	2 007 600	6 147 800	8 070 900
Difference	187 900	448 700	1 922 500	2 513 600
Difference %	14.8	18.3	23.8	23.7
Recovery %	85.2	81.7	76.2	76.3

(as of 1 January 2017, tonnes U; Red Book 2018)

Identified resources (tU)	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Total in situ	1 294 700	2 618 000	8 122 100	10 652 900
Total recoverable	1 057 700	2 079 500	6 142 200	7 988 600
Difference	237 000	538 500	1 979 900	2 664 300
Difference %	18.3	20.6	24.4	25.0
Recovery %	81.7	79.4	75.6	75.0

(as of 1 January 2015, tonnes U; Red Book 2016)

Identified resources (tU)	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Total in situ	841 000	2 695 300	7 659 400	10 188 700
Total recoverable	646 900	2 124 700	5 718 400	7 641 600
Difference	194 100	570 600	1 941 000	2 547 100
Difference %	23.1	21.2	25.3	25.0
Recovery %	76.9	78.8	74.7	75.0

* In Red Book editions 2016, 2018, and 2020, the percent difference and percent recovery are in error, and are here corrected. ** Note that tonnes U values in this table are rounded to the nearest 100 tonnes, independently, at the country and cost range level. Therefore, these cost range totals do not exactly match totals for these cost ranges as shown in other tables relating to uranium resources in this report.

Table 1.3a. **Reasonably assured recoverable resources**

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Algeria(a,b)	0	0	0	19 500
Argentina	0	7 000	10 500	10 500
Australia	NA	NA	1 238 700	1 317 800
Botswana*	0	0	20 400	20 400
Brazil(b)	138 100	155 900	155 900	155 900
Canada	0	282 300	489 700	649 000
Chile*(a,b,c)	0	0	0	600
China*(b,c,d)	31 800	55 600	107 600	111 100
Congo, Dem. Rep.*(a,b,c)	0	0	0	1 400
Czech Republic	0	0	800	50 800
Denmark/Greenland(b)	0	0	0	51 400
Finland(a,b)	0	0	1 200	1 200
Gabon(a,c)	0	0	4 800	4 800
Germany(a)	0	0	0	3 000
Greece(a,c)	0	0	0	1 000
Guyana(a,b)	0	0	0	2 400
India(b,e)	NA	NA	NA	213 000
Indonesia(b,f)	0	1 500	5 500	5 500
Iran, Islamic Republic of*(b,c)	0	0	3 200	3 200
Italy(a,c)	0	4 800	4 800	4 800
Japan(a)	0	0	6 600	6 600
Jordan(b)	0	0	6 000	6 000
Kazakhstan(b)	252 000	316 400	367 800	387 400
Malawi*	0	0	7 700	12 000
Mali*(b)	0	0	5 000	5 000
Mauritania*	0	0	6 500	6 700
Mexico(b)	0	0	1 800	1 800
Mongolia(g)	0	7 600	66 200	66 200
Namibia	0	11 800	307 200	322 800
Niger*	0	14 600	257 500	334 800
Paraguay*(b)	0	0	3 000	3 000
Peru*(b)	0	14 000	14 000	14 000
Portugal(a,b,g)	0	3 600	4 800	4 800
Romania*(a,c)	0	0	3 000	3 000
Russia(f)	0	20 600	206 400	251 900
Slovak Republic(a,b)	0	8 800	8 800	8 800
Slovenia(a,b)	0	1 700	1 700	1 700
Somalia*(a,b,c)	0	0	0	5 000
South Africa*	0	166 300	236 000	255 700

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Table 1.3a. **Reasonably assured recoverable resources** *(cont'd)*

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Spain[(b)]	8 100	19 100	19 100	19 100
Sweden*[(a,b)]	0	0	4 900	4 900
Tanzania*[(f)]	0	38 300	39 700	39 700
Türkiye[(b,f,g)]	0	0	3 000	3 000
Ukraine	0	45 200	73 300	120 600
United States[(b)]	0	9 000	59 400	112 200
Uzbekistan*	27 200	27 200	49 200	49 200
Viet Nam*[(a,b)]	0	0	0	900
Zambia*	0	0	12 800	12 800
Zimbabwe[(a,b,c)]	0	0	0	1 400
Total[(h)]	457 200	1 211 300	3 814 500	4 688 300

* Secretariat estimate. ** Note that tonnes U values in this table are rounded to the nearest 100 tonnes, independently, at the country and cost range level. Therefore, these cost range totals do not exactly match totals for these cost ranges as shown in other tables relating to uranium resources in this report. (a) Assessment not made within the last five years. (b) In situ resources were adjusted by the Secretariat to estimate recoverable resources using recovery factors provided by countries or estimated by the Secretariat according to the expected production method (Appendix 3). (c) Not reported in 2021 responses, data from previous Red Book. (d) Updated recovery factors. (e) Cost data not provided, therefore resources are reported in the <USD 260 kgU category. (f) Assessment partially made within the last five years. (g) Updated to report recoverable resources. (h) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for reasons of confidentiality, whereas other countries that have never, or not recently, hosted uranium mining, may be underestimating mining costs.

Table 1.3b. **Reasonably assured in situ resources**

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Algeria[(a)]	0	0	0	26 000
Argentina[(b)]	0	9 600	14 400	14 400
Australia[(b)]	NA	NA	1 907 500	2 076 300
Botswana*[(b)]	0	0	32 900	32 900
Brazil	184 300	209 700	209 700	209 700
Canada[(b)]	0	293 100	525 100	744 400
Chile*[(a,b)]	0	0	0	700
China*[(c)]	45 400	79 100	149 800	154 500
Congo, Dem. Rep.*[(a,c)]	0	0	0	1 900
Czech Republic[(b)]	0	0	1 300	83 800
Denmark/Greenland	0	0	0	102 800
Finland[(a)]	0	0	1 500	1 500
Gabon[(a,b,c)]	0	0	6 400	6 400
Germany[(a,b)]	0	0	0	4 000
Greece[(a,b,c)]	0	0	0	1 300

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Table 1.3b. **Reasonably assured in situ resources** *(cont'd)*

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Guyana[a]	0	0	0	3 200
India[d]	NA	NA	NA	282 400
Indonesia[e]	0	2 000	7 400	7 400
Iran, Islamic Republic of*[c]	0	0	4 300	4 300
Italy[a,b,c]	0	6 400	6 400	6 400
Japan[a,b]	0	0	7 800	7 800
Jordan	0	0	8 000	8 000
Kazakhstan	283 100	355 700	414 700	438 300
Malawi*[b]	0	0	9 500	15 700
Mali*	0	0	6 700	6 700
Mauritania*[b]	0	0	7 500	7 900
Mexico	0	0	2 500	2 500
Mongolia[b]	0	10 100	88 200	88 200
Namibia[b]	0	14 700	384 000	403 500
Niger*[b,f]	0	18 000	317 900	413 400
Paraguay*	0	0	3 400	3 400
Peru*	0	20 000	20 000	20 000
Portugal[a]	0	4 500	6 000	6 000
Romania*[a,b,c]	0	0	4 000	4 000
Russia[b,e]	0	27 500	257 200	327 100
Slovak Republic[a]	0	10 900	10 900	10 900
Slovenia[a]	0	2 200	2 200	2 200
Somalia*[a,c]	0	0	0	6 700
South Africa*[b]	0	229 400	324 600	351 500
Spain	9 800	23 000	23 000	23 000
Sweden*[a]	0	0	6 500	6 500
Tanzania*[b,e]	0	47 900	49 600	49 600
Türkiye[e]	0	0	4 300	4 300
Ukraine[b]	0	51 800	83 700	137 200
United States	0	12 000	79 200	149 500
Uzbekistan*[b]	34 100	34 100	61 800	61 800
Viet Nam*[a]	0	0	0	1 200
Zambia*[b]	0	0	14 100	14 100
Zimbabwe[a,c]	0	0	0	1 800
Total[g]	556 700	1 461 700	5 064 000	6 337 100

* Secretariat estimate. ** Note that tonnes U values in this table are rounded to the nearest 100 tonnes, independently, at the country and cost range level. Therefore, these cost range totals do not exactly match totals for these cost ranges as shown in other tables relating to uranium resources in this report. (a) Assessment not made within the last five years. (b) Recoverable resources were adjusted by the Secretariat to estimate in situ resources using recovery factors provided by countries or estimated by the Secretariat according to the expected production method (Appendix 3). (c) Not reported in 2021 responses, data from previous Red Book. (d) Cost data not provided, therefore resources are reported in the <USD 260/kgU category. (e) Assessment partially made within the last five years. (f) Updated recovery factors. (g) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for reasons of confidentiality, whereas other countries that have never, or not recently, hosted uranium mining, may be underestimating mining costs.

Table 1.4a. **Inferred recoverable resources**

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Argentina	2 400	12 300	23 800	24 800
Australia	NA	NA	445 400	642 000
Bolivia[(a,b)]	0	0	0	1 400
Botswana*	0	0	66 800	66 800
Brazil [(b)]	0	73 500	120 900	120 900
Canada	0	10 000	98 900	216 400
Central African Republic*[(b)]	0	0	0	29 200
Chad*[(a,b,c,d)]	0	0	0	2 400
Chile*[(a,b,c)]	0	0	0	900
China*[(b,c,e)]	41 400	76 900	116 400	133 600
Congo, Dem. Rep.*[(a,b,c)]	0	0	0	1 300
Czech Republic	0	0	0	68 300
Denmark/Greenland[(b)]	0	0	0	62 600
Egypt[(b)]		0	400	1 900
Gabon[(a,c)]	0	0	0	1 000
Germany [(a)]	0	0	0	4 000
Greece[(a,c)]	0	0	0	6 000
Guyana[(a,b)]	0	0	0	2 200
Hungary[(b)]	0	0	0	16 700
India[(b,d)]	NA	NA	NA	8 000
Indonesia[(b,f)]	0	0	3 000	3 000
Iran, Islamic Republic of*[(b,c)]	0	0	4 200	4 200
Italy[(a,c)]	0	1 300	1 300	1 300
Jordan[(b)]	0	0	46 500	46 500
Kazakhstan[(b)]	250 000	415 700	447 500	487 300
Malawi*	0	0	1 800	4 300
Mali*[(b)]	0	0	3 900	3 900
Mauritania*	0	0	12 300	19 300
Mexico[(b)]	0	0	1 800	3 200
Mongolia[(g)]	0	9 300	78 400	78 400
Namibia	0	7 900	162 900	186 700
Niger*	0	0	53 600	133 200
Paraguay*[(b)]	0	0	1 400	1 400
Peru*[(b)]	0	19 400	19 400	19 400
Portugal[(a,b,g)]	0	0	800	800
Romania*[(a,c)]	0	0	3 600	3 600
Russia[(f)]	0	14 400	274 500	405 000
Senegal*[(b)]	0	0	0	1 100
Slovak Republic[(a,b)]	0	3 900	6 700	6 700

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Table 1.4a. **Inferred recoverable resources** *(cont'd)*

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Slovenia(a,b)	0	3 800	7 500	7 500
Somalia*(a,b,c)	0	0	0	2 600
South Africa*	0	61 700	84 800	189 000
Spain(b)	0	9 400	9 400	9 400
Sweden*(a,b)	0	0	4 700	4 700
Tanzania*(f)	0	8 500	18 500	18 500
Türkiye(b,f,g)	0	0	8 700	9 700
Ukraine	0	26 700	33 800	64 800
Uzbekistan*	24 900	24 900	82 100	82 100
Viet Nam*(a,b)	0	0	0	3 000
Zambia*	0	0	18 200	18 200
Total(h)	318 700	779 600	2 263 900	3 229 200

* Secretariat estimate. ** Note that tonnes U values in this table are rounded to the nearest 100 tonnes, independently, at the country and cost range level. Therefore, these cost range totals do not exactly match totals for these cost ranges as shown in other tables relating to uranium resources in this report. (a) Assessment not made within the last five years. (b) In situ resources were adjusted by the Secretariat to estimate recoverable resources using recovery factors provided by countries or estimated by the Secretariat according to the expected production method (Appendix 3). (c) Not reported in 2021 responses, data from previous Red Book. (d) Cost data not provided, therefore resources are reported in the <USD 260/kgU category. (e) Updated recovery factors. (f) Assessment partially made within the last five years. (g) Updated to report recoverable resources. (h) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for confidentiality concerns, whereas other countries that have never, or not recently, hosted uranium mining, may be underestimating mining costs.

Table 1.4b. **Inferred in situ resources**

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Argentina(a)	3 200	16 300	31 800	33 100
Australia(a)	NA	NA	700 900	985 100
Bolivia(b)	0	0	0	1 700
Botswana*(a)	0	0	107 700	107 700
Brazil	0	104 900	172 600	172 600
Canada(a)	0	11 500	113 300	247 900
Central African Republic*	0	0	0	36 500
Chad*(b,c,d)	0	0	0	3 200
Chile*(b,c)	0	0	0	1 200
China*(c)	59 200	109 100	162 000	185 000
Congo, Dem. Rep.*(b,c)	0	0	0	1 700
Czech Republic (a)	0	0	0	113 500
Denmark/Greenland	0	0	0	125 100
Egypt	0	0	500	2 500
Gabon(a,b,c)	0	0	0	1 300

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Table 1.4b. **Inferred in situ resources** *(cont'd)*

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes**)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Germany[(a,b)]	0	0	0	5 300
Greece[(a,b,c)]	0	0	0	8 000
Guyana[(b)]	0	0	0	2 900
Hungary	0	0	0	22 200
India[(d)]	NA	NA	NA	10 500
Indonesia[(e)]	0	0	4 100	4 100
Iran, Islamic Republic of*[(c)]	0	0	5 500	5 500
Italy[(a,b,c)]	0	1 700	1 700	1 700
Jordan	0	0	62 000	62 000
Kazakhstan	280 800	467 400	504 600	552 600
Malawi*[(a,f)]	0	0	2 300	5 600
Mali*	0	0	5 200	5 200
Mauritania*[(a)]	0	0	14 300	23 700
Mexico	0	0	2 500	4 300
Mongolia[(a)]	0	12 400	104 100	104 100
Namibia[(a)]	0	9 900	203 600	233 400
Niger*[(a,f)]	0	0	66 200	172 600
Paraguay*	0	0	1 600	1 600
Peru*	0	27 700	27 700	27 700
Portugal[(b)]	0	0	1 000	1 000
Romania*[(a,b,c)]	0	0	4 800	4 800
Russia[(a,e)]	0	19 200	333 000	513 800
Senegal*	0	0	0	1 500
Slovak Republic[(b)]	0	4 900	8 400	8 400
Slovenia[(b)]	0	5 000	10 000	10 000
Somalia*[(a,b,c)]	0	0	0	3 500
South Africa* [(a)]	0	82 200	112 200	260 600
Spain	0	11 400	11 400	11 400
Sweden*[(b)]	0	0	6 300	6 300
Tanzania*[(a,e)]	0	10 600	23 200	23 200
Türkiye[(e)]	0	0	10 900	12 400
Ukraine[(a)]	0	30 200	38 200	73 900
Uzbekistan*[(a)]	31 100	31 100	108 500	108 500
Viet Nam*[©]	0	0	0	4 000
Zambia*[(a)]	0	0	20 100	20 100
Total[(g)]	374 300	955 500	2 982 200	4 334 500

* Secretariat estimate. ** Note that tonnes U values in this table are rounded to the nearest 100 tonnes, independently, at the country and cost range level. Therefore, these cost range totals do not exactly match totals for these cost ranges as shown in other tables relating to uranium resources in this report. (a) Recoverable resources were adjusted by the Secretariat to estimate in situ resources using recovery factors provided by countries or estimated by the Secretariat according to the expected production method (Appendix 3). (b) Assessment not made within the last five years. (c) Not reported in 2021 responses, data from previous Red Book. (d) Cost data not provided, therefore resources are reported in the <USD 260/kgU category. (e) Assessment partially made within the last five years. (f) Updated recovery factors. (g) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for confidentiality concerns, whereas other countries that have never, or not recently, hosted uranium mining, may be underestimating mining costs.

Table 1.5. **Major identified recoverable resource changes by country**

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes*)

Country	Resource category	2019	2021	Changes	Reasons
Australia	**RAR**				RAR increases and INF decreases due to reported Olympic Dam resource figures and updated uranium recoverability information for some deposits.
	<USD 130/kgU	1 183 900	1 238 700	54 800	
	<USD 260/kgU	1 284 800	1 317 800	33 000	
	Inferred				
	<USD 130/kgU	508 800	445 400	-63 400	
	<USD 260/kgU	764 600	642 000	-122 600	
Canada	**RAR**				Loss of USD <40/kgU RAR due to combined effects of inflation, changes in cut-off grades and mining depletion. Increase in USD<80/kgU RAR in part due to the addition of Phoenix and Heldeth Túé deposits that are proposed to be mined using lower cost ISL methods.
	<USD 40/kgU	258 500	0	-258 500	
	<USD 80/kgU	258 500	282 300	23 800	
	<USD 130/kgU	461 600	489 700	28 100	
	<USD 260/kgU	652 200	649 000	-3 200	
	Inferred				
	<USD 40/kgU	1 900	0	-1 900	
	<USD 80/kgU	10 900	10 000	-900	
	<USD 130/kgU	103 300	98 900	-4 400	
	<USD 260/kgU	220 800	216 400	-4 400	
Central African Republic	**RAR**				Re-evaluation of Bakouma Basin deposits results in a decrease of overall recoverable uranium and a downgrade from RAR to INF.
	<USD 130/kgU	32 000	0	-32 000	
	<USD 260/kgU	32 000	0	-32 000	
	Inferred				
	<USD 260/kgU	0	36 400	36 400	
Hungary	**Inferred**				Private company exploration adds to the existing total of Mecsek Mountain resources.
	<USD 260/kgU	13 500	16 700	3 200	
India	**RAR**				Increase due to resource additions in the southern Cuddapah Basin and extensions of known deposits in the Singhbhum Shear Zone, Bhima Basin, and North Delhi Fold Belt.
	<USD 260/kgU	188 000	213 000	25 000	
Kazakhstan	**RAR**				Overall decreases in Identified Resources a result of mining depletion and the transfer of Kosachinoye deposit high-cost resources (OP and UG; >100 000 tU) to the sub-economic category, balanced by increases in Inferred Resources (> 55 00 tU) at sites No. 6 and No. 7 of the Budennovskoye deposit.
	<USD 40/kgU	272 200	252 000	-20 200	
	<USD 80/kgU	343 800	316 400	-27 400	
	<USD 130/kgU	445 100	367 800	-77 300	
	<USD 260/kgU	464 700	387 400	-77 300	
	Inferred				
	<USD 40/kgU	258 400	250 000	-8 400	
	<USD 80/kgU	374 600	415 700	41 100	
	<USD 130/kgU	461 700	447 500	-14 200	
	<USD 260/kgU	504 400	487 300	-17 100	

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Table 1.5. **Major identified recoverable resource changes by country** *(cont'd)*

(as of 1 January 2021, tonnes U, rounded to nearest 100 tonnes*)

Country	Resource category	2019	2021	Changes	Reasons
Malawi	**RAR**				RAR increase as a result of a new resource evaluation by Lotus Resources Ltd, after its acquisition of the Kaylekera uranium project.
	<USD 130/kgU	4 400	7 700	3 300	
	<USD 260/kgU	9 700	12 000	2 300	
	Inferred				
	<USD 130/kgU	1 800	1 800	0	
	<USD 260/kgU	4 600	4 400	-200	
Mauritania	**RAR**				Drilling and analyses done to complete a Tiris Project feasibility study converts Inferred Resources to Reasonable Assured Resources.
	<USD 130/kgU	5 700	6 500	800	
	<USD 260/kgU	5 900	6 700	800	
	Inferred				
	<USD 130/kgU	11 500	12 300	800	
	<USD 260/kgU	18 500	19 300	800	
Mongolia	**RAR**				Additional resources were identified during recent exploration of sandstone-type deposits amenable to ISL while resources for underground and open-pit mining were moved to higher cost categories.
	<USD 80/kgU	25 100	7 600	-17 500	
	<USD 130/kgU	45 500	66 200	20 700	
	<USD 260/kgU	45 500	66 200	20 700	
	Inferred				
	<USD 80/kgU	20 400	9 300	-11 100	
	<USD 130/kgU	62 500	78 400	15 900	
	<USD 260/kgU	62 500	78 400	15 900	
Namibia	**RAR**				RAR and IR increases the result of additional resources identified at the Tumas and Wings deposits balanced by mining depletion at the Husab and Rössing mines, along with re-estimation of historical resources at Trekkopje.
	<USD 80/kgU	0	11 800	11 800	
	<USD 130/kgU	279 400	307 200	27 800	
	<USD 260/kgU	320 700	322 800	2 100	
	Inferred				
	<USD 80/kgU	0	7 900	7 900	
	<USD 130/kgU	168 900	162 900	-6 000	
	<USD 260/kgU	183 500	186 700	3 200	
Niger	**RAR**				Ongoing exploration defines additional resources at existing mines and deposits under development, mainly at Somaïr and Dasa.
	<USD 80/kgU	9 900	14 600	4 700	
	<USD 130/kgU	238 700	257 500	18 800	
	<USD 260/kgU	315 500	334 800	19 300	
	Inferred				
	<USD 130/kgU	37 700	53 600	15 900	
	<USD 260/kgU	123 900	133 200	9 300	

* Note that tonnes U values in this table are rounded to the nearest 100 tonnes, independently, at the country and cost range level. Therefore, these cost range totals do not exactly match totals for these cost ranges as shown in other tables relating to uranium resources in this report.

Reasonably assured resources amount to 59% of the identified resource total, a less than 1% increase compared to the last reporting period. As of 1 January 2021, low-cost RAR and IR comprised <10% of total RAR and IR, declining by 6% and 0.2% respectively from 2019.

Australia reported increased RAR and decreased IR in the higher cost categories (<USD 130/kgU and 260/kgU) due to Olympic Dam resource figure updates and reassessment of recoverability information for some deposits. Canada reported a significant decline in low-cost (<USD 40/kgU) RAR owing to the combined effects of increased mining costs and cut-off grade change that reflects a uranium price <USD 80/kgU. The Central African Republic reported reduced high-cost (<USD 260/kgU) resources, downgraded from RAR to IR, resulting from the reassessment of resources at the Bakouma deposit. In Hungary, additional high-cost (<USD 260/kgU) Mecsek Mountain resources identified through private company exploration efforts were incorporated into national resource totals, leading to an increase in IR. In India, ongoing exploration efforts led to a 13% increase in high-cost (<USD 260/kgU) RAR, compared to 2019. Kazakhstan reported decreased RAR and IR (with the exception of IR <USD 80/kgU category) resulting from ongoing mining depletion and the transfer of high-cost open-pit and underground Kosachinoye field resources to the subeconomic category, balanced by increases in IR at sites No. 6 and No. 7 of the Budennovskoye field. Updated resource evaluations by the new owner of the Kayelekera uranium project in Malawi led to increases in higher cost (<USD 130/kgU and 260/kgU) RAR. Ongoing exploration at the Tirus deposit in Mauritania led to increases in higher cost (<USD 130/kgU and 260/kgU) RAR and IR. In Mongolia, ongoing exploration led to the identification of higher cost (<USD 130/kgU and 260/kgU) RAR and IR and reassessment of mining costs led to a shift of resources into higher cost categories. Ongoing exploration in Namibia boosted RAR and IR resource totals in all categories (with the exception of IR <USD 130/kgU), including the addition of lower cost (<USD 80/kgU) RAR and IR resulting from the discovery of the first deposit (Wings) in the country potentially amenable to in situ leaching (ISL) mining. Decreases in RAR and IR occurred across all cost categories in China and Türkiye owing to recovery factor reductions in both countries resulting from Secretariat assessment of local geologic conditions.

Australia still dominates the world's uranium resources with 28% of the total identified resources at <USD 130/kgU and 25% of identified resources in the highest cost category (<USD 260/kgU). However, 68% of Australia's uranium resources (and 17% of global identified resources) are attributed to the world-class polymetallic Fe-oxide breccia complex, the Olympic Dam deposit, where uranium is mined as a co-product. Kazakhstan remains a distant second with approximately 13% available at <USD 130/kgU and 11% in the <USD 260/kgU cost category. Canada's share has been reduced slightly since the last reporting period to about 10% in the <USD 130/kgU category and 11% in the <USD 260/kgU category. All remaining countries have less than a 10% share in these higher cost categories. There are 15 countries that represent approximately 95% of the total identified resources in the <USD 130/kgU cost category (see Figure 1.1).

With respect to the lower cost categories, Australia does not report any resources at these costs and thus Kazakhstan leads with 64% of lowest cost resources (<USD 40/kgU), followed by Brazil (18%), China (9%), Uzbekistan (7%), Spain (1%) and Argentina (<1%), the only six countries reporting resources in this cost category for this edition. In the <USD 80/kgU cost category, Kazakhstan holds a 37% share, followed by Canada (15%), Brazil and South Africa (12%), China (7%), Uzbekistan (3%) and Spain (1%), with Argentina, Mongolia, Niger each holding <1% shares in this cost category. Readers are cautioned concerning these lower cost resource estimates (<USD 40/kgU, <USD 80/kgU), since Australia does not report resources in these cost categories, the United States does not report IR, and some countries that have never (or have not recently) hosted uranium mining may be underestimating mining costs.

Starting in the 2016 edition, a summary has been prepared of worldwide in situ identified conventional resources (see Tables 1.2b, 1.3b and 1.4b). Table 1.2c is a summary comparison of in situ identified resources and recoverable identified resources by cost category. Overall, there is a 17% to 26% increase in the resource figures when they are reported as in situ. This corresponds to average recoveries ranging from approximately 74% to 83%. Total identified in situ resources increased marginally (<1%) from 10 584 500 tU reported in the last edition to 10 671 800 tU for this edition as only three countries provided both in situ and recoverable figures, and conversions produced by the application of generic recovery factors (see Appendix 3) as NEA/IAEA estimates were, in the cases of China and Türkiye, adjusted by the IAEA Secretariat to be more commensurate with the geological settings of the uranium deposits and planned mining technologies in these countries.

Reporting in situ resources provides a more optimistic view of the available resource base and provides an indication of how the resource base could be increased with improvements in mining and processing methods that would lead to better recovery. Nonetheless, recoverable resources still provide the best and more realistic estimate of uranium supply.

Distribution of resources by production method

For this edition of the Red Book, countries once again were asked to report identified resources by cost categories and by the expected production method: open-pit or underground mining, in situ leaching (ISL, sometimes referred to as in situ recovery, or ISR), heap leaching or in-place leaching, co-product/by-product, or unspecified.

In the cost category <USD 40/kgU, although underground and open-pit mining remain important production methods for RAR (Table 1.6) in Brazil (where resources for open-pit mining have been developed in recent years), ISL (acid) has surpassed the combined total of underground and open-pit mining, as well as ISL alkaline and co-product/by-product production, in this, the lowest cost category of high confidence resources. Low-cost resources amenable to production by ISL, mainly in Kazakhstan, and to a lesser extent China and Uzbekistan, make the most significant contributions. Resources suited for co-product/by-product production and underground mining in Brazil make up the remainder, followed by alkaline ISL (China). The total of low-cost resources is likely underestimated owing to the difficulty in assigning mining costs accurately in the co-product/by-product category, notably in Australia.

Table 1.6. **Reasonably assured recoverable resources by production method**

(as of 1 January 2021, tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Open-pit mining	16 153	104 832	900 196	1 047 462
Underground mining	59 049	384 885	971 898	1 399 002
In situ leaching acid	291 556	434 686	544 941	601 902
In situ leaching alkaline	19 460	26 852	75 575	75 575
Co-product/by-product	71 050	255 167	1 280 228	1 434 468
Unspecified	0	4 800	41 546	129 659
Total	457 268	1 211 222	3 814 384	4 688 068

In the <USD 80/kgU category, resources amenable to production by ISL (Canada, China, Kazakhstan, Mongolia, Namibia, Russia, Ukraine and Uzbekistan) and underground mining methods (mainly Brazil, Canada, Ukraine and the United States) make the most significant contribution, with by-product/co-product category (Brazil and South Africa) and open-pit mining (Argentina, Brazil, Niger, Peru, Spain and Tanzania) rising in importance.

In the <USD 130/kgU category, resources in the by-product/co-product category are greatest, predominately a result of the Olympic Dam deposit in Australia, with underground (mainly Australia, Brazil, Canada, Russia and Ukraine) and open-pit mining (mainly Australia, Namibia and Niger) making the most significant contributions of the remaining production methods, followed by ISL acid.

In the <USD 260/kgU category, the underground (mainly Australia, India, Canada and Russia) and co-product/by-product (Australia, Brazil, Greenland, Russia and South Africa) production methods continue to lead, followed by open-pit mining (mainly Australia, Namibia and Niger). Canada holds the largest resource total for underground mining while Namibia and Niger make the largest contributions in the open-pit production category. ISL makes an important contribution in all cost categories, with Kazakhstan being the dominant player for ISL acid and China and the United States for ISL alkaline.

The pattern of resource distribution by production method for IR (Table 1.7) is similar to that for RAR. In the lowest cost categories (<USD 40/kgU and <USD 80/kgU), resources amenable to ISL production dominate, principally in Kazakhstan. In the <USD 130/kgU category, ISL acid continues to lead, dominated by Kazakhstan and Uzbekistan, but is followed closely by co-product/by-product (Australia, Brazil and South Africa), open-pit (mainly Botswana, Jordan, Namibia and Niger) and underground mining (mainly Australia, Canada, China, Russia and Ukraine). In the highest cost category (<USD 260/kgU), underground mining (mainly Canada and Russia) leads with co-product/by-product (mainly Australia, Brazil, Greenland and South Africa), open pit (mainly Australia and Namibia) and ISL (mainly Kazakhstan, followed by Australia, the Czech Republic and Uzbekistan) making significant contributions. Since the United States does not report IR, the ISL alkaline category is under-represented in Table 1.7.

Table 1.7. **Inferred recoverable resources by production method**

(as of 1 January 2021, tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Open-pit mining	2 430	52 047	525 323	693 405
Underground mining	0	56 088	506 833	860 808
In situ leaching acid	281 646	475 729	573 836	690 313
In situ leaching alkaline	34 650	59 955	63 245	63 245
Co-product/by-product	0	94 579	520 898	718 045
Unspecified	0	41 130	73 830	203 571
Total	318 726	779 528	2 263 965	3 229 387

Distribution of resources by processing method

In 2021, countries were once again requested to report identified conventional resources by cost categories and by the expected processing method: conventional from open-pit or conventional from underground mining, ISL, in-place leaching, heap leaching from open-pit or heap leaching from underground, or unspecified. It should be noted that not all countries reported their resources according to processing method.

The overall distribution has changed somewhat since the last reporting period, owing to the reclassification of Canadian resources from the lowest cost category (<USD 40/kgU), considerably reducing the share of low-cost resources amenable to underground mining. In all but the lowest cost category for RAR, where ISL amenable resources dominate (Table 1.8), conventional processing from underground mining is the major contributor, particularly in the higher cost categories (<USD 130/kgU and <USD 260/kgU), owing principally to Australia's Olympic Dam deposit. In the higher cost categories, conventional processing from open pit and ISL make increasing contributions, but even when combined do not surpass the underground resources. Heap leaching from open-pit and underground mining become increasingly important in the higher cost categories (<USD 130/kgU and <USD 260/kgU), particularly in Botswana, Namibia and Niger.

Table 1.8. **Reasonably assured recoverable resources by processing method**

(as of 1 January 2021, tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from OP	12 103	81 673	621 140	763 073
Conventional from UG	59 049	549 571	2 143 734	2 618 995
In situ leaching acid	291 556	434 687	544 941	601 902
In situ leaching alkaline	19 460	26 852	75 575	75 575
In-place leaching*	0	0	516	5 942
Heap leaching** from OP	3 150	17 129	268 224	323 568
Heap leaching** from UG	0	5 130	25 638	29 459
Unspecified	71 950	96 180	134 616	269 554
Total	457 268	1 211 222	3 814 384	4 688 068

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

With respect to IR (Table 1.9), ISL dominates in the two lower cost categories, but in the two higher cost categories is surpassed by the underground conventional method, with conventional from open-pit mining rising in importance. Heap leaching from open pit becomes increasingly important in the higher cost categories (<USD 130/kgU and <USD 260/kgU), particularly in Botswana, Jordan and Namibia. The amount that is reported as unspecified is important because the exploration of many deposits is insufficiently advanced for any mine planning to have been carried out. Note that the United States does not report IR by processing method, leading to under-representation in the ISL alkaline category in Table 1.9.

Table 1.9. **Inferred recoverable resources by processing method**

(as of 1 January 2021, tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from OP	2 430	34 332	339 400	555 009
Conventional from UG	0	113 994	931 176	1 367 418
In situ leaching acid	281 646	475 729	573 838	690 306
In situ leaching alkaline	34 650	59 955	63 245	63 245
In-place leaching*	0	0	2 068	13 594
Heap leaching** from OP	0	19 418	139 626	151 498
Heap leaching** from UG	0	0	250	7 085
Unspecified	0	76 100	214 362	381 232
Total	318 726	779 528	2 263 965	3 229 387

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Distribution of resources by deposit type

In 2021, countries also reported identified resources by cost categories and by geological types of deposits using the deposit classification scheme introduced in the 2014 edition (Appendix 3).

Sandstone RAR, mainly in Australia, China, Kazakhstan, Niger and the United States, tops all cost categories (Table 1.10). In the higher cost categories (<USD 130/kgU and <USD 260/kgU), polymetallic iron-oxide breccia complex deposits in Australia become increasingly more important, along with Proterozoic unconformity-related resources (mainly in Canada), metasomatite (mainly in Brazil, Russia and Ukraine), intrusive (mainly Greenland, Namibia and Russia) and paleo-quartz-pebble conglomerate resources (South Africa).

Table 1.10. **Reasonably assured recoverable resources by deposit type**

(as of 1 January 2021, tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic Unconformity	0	282 327	596 683	733 862
Sandstone	311 016	501 554	996 689	1 203 406
Polymetallic Fe-Oxide Breccia Complex	0	0	969 432	1 009 928
Paleo-quartz-pebble conglomerate[(a)]	0	166 337	228 784	254 388
Granite-related	27 184	58 250	65 037	89 397
Metamorphite	0	1 522	5 979	57 182
Intrusive	0	0	226 721	346 955
Volcanic-related	0	29 779	129 074	132 007
Metasomatite	66 663	111 569	293 637	401 492
Surficial deposits	0	1 860	152 029	165 753
Carbonate	0	0	0	122 722
Collapse breccia	405	405	405	405
Phosphate	52 000	53 270	88 139	96 255
Lignite – coal	0	0	15 767	15 767
Black shale	0	0	1 690	1 690
Unspecified	0	4 349	44 318	56 859
Total	457 268	1 211 222	3 814 384	4 688 068

(a) In South Africa, Paleo-quartz-pebble conglomerate resources include tailings resource.

Similar patterns are apparent in the IR category (Table 1.11). Sandstone-hosted resources dominate all cost categories. In the lowest cost category (<USD 40/kgU), sandstone-hosted resources essentially standalone. In the higher cost categories (<USD 130/kgU and <USD 260/kgU), polymetallic iron-oxide breccia complex type deposits (Australia), metasomatite (mainly Kazakhstan, Russia and Ukraine), intrusive (mainly Greenland, Namibia and Russia) and Proterozoic unconformity-type deposits (mainly Canada) rise in importance, but still do not rival sandstone-based resources in abundance.

Table 1.11. **Inferred recoverable resources by deposit type**

(as of 1 January 2021, tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic Unconformity	0	10 025	134 177	223 004
Sandstone	318 246	567 922	864 449	1 151 760
Polymetallic Fe-Oxide Breccia Complex	0	0	366 224	435 237
Paleo-quartz-pebble conglomerate[a]	0	72 456	85 161	129 411
Granite-related	0	9 421	61 108	77 495
Metamorphite	0	720	2 988	9 220
Intrusive	0	0	122 368	244 644
Volcanic-related	480	26 423	87 684	103 871
Metasomatite	0	33 948	296 704	414 982
Surficial deposits	0	1 120	100 823	157 677
Carbonate	0	0	3 748	3 748
Collapse breccia	0	19 008	19 008	19 008
Phosphate	0	30 010	37 137	76 327
Lignite coal	0	0	2 010	72 785
Black shale	0	0	32 900	32 900
Unspecified	0	8 475	47 476	77 318
Total	318 726	779 528	2 263 965	3 229 387

(a) In South Africa, Paleo-quartz-pebble conglomerate resources include tailings resources.

Proximity of resources to production centres

Estimates on the availability of resources for near-term production in nine countries are provided by reporting the percentage of identified resources (RAR and IR) recoverable at costs of <USD 80/kgU and <USD 130/kgU that are proximal to existing and committed production centres (Table 1.12). Resources proximal to existing and committed production centres in seven of the countries listed a total of 1 228 843 tU at <USD 80/kgU (about 79% of the total resources reported in this cost category). This is a 2.4% increase over the 2019 value of 1 200 385 tU. This change over the two-year reporting period is attributed to decreased resources in this cost category in Russia, offset by increases in Canada, Kazakhstan, Namibia and Niger. Resources proximal to existing and committed production centres in the nine countries listed a total of 3 078 504 tU at <USD 130/kgU (about 62% of the total resources reported in this cost category). This is 2.6% lower than the 3 160 532 tU reported for 2019 and is the result of decreases of resources in this cost category in Australia, Namibia, Niger and Russia, offset by increases in Canada and Kazakhstan.

Table 1.12. **Identified recoverable resources proximate to existing or committed production centres***

(as of 1 January 2021, tonnes U)

Country	Reasonably assured + inferred recoverable resources at <USD 80/kgU cost category			Reasonably assured + inferred recoverable resources at <USD 130/kgU cost category		
	Total (tU)	Proximate (tU)	Proximate (%)	Total (tU)	Proximate (tU)	Proximate (%)
Australia	NA	NA	NA	1 684 097	1 347 278	80
Brazil	229 396	17 205	8	276 786	16 607	6
Canada	292 352	292 352	100	588 524	373 713	64
Iran, Islamic Rep of[a]	0	0	0	7 484	7 484	100
Kazakhstan	732 060	680 816	93	815 244	676 653	83
Namibia	19 680	0	0	470 065	239 733	51
Niger[b]	14 620	14 620	100	311 120	117 115	38
Russia	34 966	34 616	99	480 901	110 607	23
South Africa	227 993	189 234	83	320 873	189 315	59
Total	1 551 067	1 228 843	79	4 955 094	3 078 504	62

* Identified resources only in countries that reported proximity to production centres, not world total. (a) Not reported in 2021; data from previous Red Book. (b) Assumes the Dasa Project is committed.

Undiscovered resources

Undiscovered resources (prognosticated and speculative; see Appendix 3) refer to resources that are expected to occur based on geological knowledge of previously discovered deposits and regional geological mapping. *Prognosticated resources* (PR) refer to those expected to occur in known uranium provinces, generally supported by some direct evidence. *Speculative resources* (SR) refer to those expected to occur in geological provinces that may host uranium deposits. Both PR and SR require significant amounts of exploration before their existence can be confirmed and grades and tonnages can be more accurately determined. All PR and SR are reported as in situ resources (see Table 1.13).

Worldwide, reporting of PR and SR is incomplete; a total of 27 countries (including 11 NEA/IAEA estimates) reported undiscovered resources for this edition, compared to the 40 reporting RAR (including 13 NEA/IAEA estimates). Only 10 countries of those reporting updated undiscovered resource figures for this edition. Nineteen countries reported both PR and SR. Germany, Italy, Jordan, Mauritania, Poland, Venezuela and Zimbabwe reported only SR, whereas Bulgaria, Egypt, Greece, Hungary, Indonesia, Paraguay, Portugal, the Slovak Republic, Slovenia and Uzbekistan reported only PR.

In addition to a few recently updated assessments, some countries with significant resource potential, such as Australia and the United States, do not report undiscovered resources. A number of different quantitative mineral resource assessment approaches and integrated quantitative and mineral prospectivity mapping methods have been investigated and applied at local, regional and national scales, including in Australia (for surficial-type uranium deposits, using a variety of integrated methodologies), and the United States (for sandstone-hosted and surficial-type uranium deposits, using integrated mineral prospectivity mapping and 3-Part quantitative methods). For additional details on such methods and applications, see IAEA (2018a).

Table 1.13. **Undiscovered (prognosticated and speculative) in situ resources**

(as of 1 January 2021, tonnes U)

Country	Prognosticated resources			Speculative resources			Total SR
	Cost ranges			Cost ranges			
	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	<USD 130/kgU	<USD 260/kgU	Cost range unassigned	
Argentina	NA	20 100	20 700	NA	79 500	NA	79 500
Brazil[(a)]	300 000	300 000	300 000	NA	NA	500 000	500 000
Bulgaria	NA	NA	25 000	NA	NA	NA	NA
Canada[(a)]	50 000	150 000	150 000	700 000	700 000	0	700 000
Chile*[(b)]	0	0	2 300	0	0	2 360	2 360
China[(b,c)]	3 600	3 600	3 600	4 100	4 100	NA	4 100
Colombia[(b)]	NA	11 000	11 000	217 000	217 000	NA	217 000
Czech Republic	0	0	222 910	0	0	17 000	17 000
Egypt	0	13 600	13 600	NA	NA	NA	NA
Germany[(a)]	NA	NA	NA	NA	NA	74 000	74 000
Greece[(b)]	6 000	6 000	6 000	NA	NA	NA	NA
Hungary	0	0	14 800	0	0	0	0
India	NA	NA	144 200	NA	NA	59 400	59 400
Indonesia	0	0	37 300	0	0	0	0
Iran, Islamic Republic of[(b)]	0	9 800	9 800	0	0	48 100	48 100
Italy[(b)]	0	0	0	10 000	10 000	NA	10 000
Jordan[(a)]	0	0	0	0	50 000	NA	50 000
Kazakhstan	85 200	113 200	114 700	191 900	219 400	NA	219 400
Mauritania*	0	0	0	NA	NA	19 000	19 000
Mexico[(b)]	NA	3 000	3 000	NA	NA	10 000	10 000
Mongolia[(a)]	13 300	13 300	13 300	1 319 000	1 319 000	NA	1 319 000
Namibia	0	0	57 000	0	0	150 700	150 700
Niger	0	13 600	13 600	0	51 300	0	51 300
Paraguay	0	10 800	10 800	0	0	0	0
Peru	6 600	19 800	19 800	45 400	45 400	0	45 400
Poland	0	0	0	0	0	20 000	20 000
Portugal[(a)]	1 000	1 500	1 500	NA	NA	NA	NA
Romania[(b)]	NA	3 000	3 000	3 000	3 000	NA	3 000
Russia	0	110 650	164 700	148 200	528 600	0	528 600
Slovak Republic	0	3 700	10 900	0	0	0	0
Slovenia[(a)]	0	1 060	1 060	0	0	0	0
South Africa[(b)]	0	74 000	159 000	243 000	411 000	280 000	691 000
Ukraine[(a)]	0	8 400	22 500	0	120 000	255 000	375 000
United States	NA	NA	NA	NA	NA	NA	NA
Uzbekistan*	24 800	24 800	24 800	NA	NA	NA	NA
Venezuela[(b)]	NA	NA	NA	0	0	163 000	163 000
Viet Nam[(a)]	NA	NA	81 200	NA	NA	321 600	321 600
Zimbabwe[(b)]	0	0	0	25 000	25 000	NA	25 000
Total	490 500	914 910	1 662 070	2 906 600	3 783 300	1 920 160	5 703 460

NA = Data not available. * Secretariat estimate; no change since last edition. (a) Reported in 2021 responses, but values have not been updated within last 5 years. (b) Not reported in 2021 response, data from previous Red Book. (c) China has conducted a systematic nationwide uranium resource prediction and evaluation with prognosticated resources estimated to be around 2 million tU. Since a cost range is not assigned to these resources, they are not included in this table.

The US Geological Survey in the United States, for example, is now re-estimating undiscovered resources using a combination of mineral prospectivity mapping and the “3-Part” form of quantitative mineral resource assessment (Singer et al., 2010). Two assessments have been completed, estimating about 84 500 tU recoverable in the Texas Coastal Plain and 15 000 tU in situ in the Southern High Plains region (Mihalasky et al., 2015; Hall et al., 2017). However, this recent work is yet to be classified into either PR or SR categories and, as a result, is not reported in Table 1.13. As of 2022, only about 10% of the undiscovered uranium resources in the United States have been recently reassessed. There is interest in completing more assessments and plans have been made, but the assessments have not yet been conducted.

China, as well, reports significant resource potential not included in Table 1.13. A systematic nationwide uranium resource prediction and evaluation estimated that PR amounted to 2 million tU. Since a cost range is not assigned to these resources, they are not included in Table 1.13.

Total PR in the highest cost category (<USD 260/kgU) amounted to 1.662 million tU, a 3.5% increase compared to 2019. In the lower cost categories (i.e. <USD 80/kgU and <USD 130/kgU), the PR totals increased by <1% and 3.7% respectively, compared to the last reporting period. Increases were reported for Argentina and Egypt in the <USD 80/kgU and <USD 130/kgU cost categories, Hungary and India in the <USD 260/kgU cost category and Kazakhstan in all three cost categories (<USD 80/kgU, <USD 130/kgU and <USD 260/kgU). Decreases were reported for Peru in the <USD 130/kgU and <USD 260/kgU cost categories and Russia in the highest cost category (<USD 260/kgU). No changes have been reported for the remaining countries since the last reporting period.

Speculative resources in the <USD 130/kgU and <USD 260/kgU cost categories increased by 1.1% and 1.3% respectively, compared to 2019, due to increases reported by Peru and Kazakhstan, offset by decreased SR in the highest cost category (<USD 260/kgU) recorded by Russia. The unassigned cost category increased overall by 1.7%, owing to increases reported by India, Kazakhstan and Namibia, offset by reductions in Russia. The total SR in the <USD 130/kgU cost category increased by 1.1% since the last report, with increases reported by Kazakhstan and Peru. No other countries reported changes in this cost category.

High-cost (<USD 260/kgU) PR and total SR amount to a combined total of 7 365 530 tU, an increase of 2% from the 7 218 540 tU reported in 2019.

Other resources and materials

Conventional resources are defined as resources from which uranium is recoverable as a primary product, a co-product or an important by-product, while unconventional resources are resources from which uranium is only recoverable as a minor by-product, such as uranium associated with phosphate rocks, non-ferrous ores, carbonatite, black shale and lignite (see Appendix 3 for definitions).

In essence, conventional resources are the types of resources that have historically been mined, whereas unconventional resources have only been mined occasionally, although there are exceptions. Moreover, the distinction between conventional and unconventional resources is not consistently defined: some countries consider unconventional resources to be a part of their conventional resource endowment: 1) if uranium grades are relatively high; 2) if uranium was the principal exploration target; or 3) if conventional resources are not available in the quantities needed to meet domestic requirements.

Historically, phosphate deposits (Barthel, 2005) are the only unconventional resources from which a significant amount of uranium has been produced. Processing of Moroccan phosphate rock in Belgium produced 690 tU between 1975 and 1999, and about 17 150 tU were recovered in the United States from Florida phosphate rocks between 1954 and 1962. As much as 40 000 tU were also recovered from processing marine organic deposits (essentially concentrations of ancient fish bones in Kazakhstan). In the former German Democratic Republic, low grade (<0.006% U) Silurian black shales in the Ronneburg ore field were a source of significant quantities of uranium (nearly 100 000 tU) between 1950 and 1990 (IAEA, 2020). However, except for Belgian production from phosphates, production from such low-grade unconventional resources was undertaken principally to meet strategic demand when uranium prices were high and, in some cases, production costs were not considered important.

Most of the unconventional uranium resources reported to date are associated with uranium in black shales and phosphate rocks, but other potential sources exist (e.g. seawater, discussed below). Estimates of uranium resources associated with marine and organic phosphorite deposits point to the existence of almost 9 million tU in four countries alone: Jordan, Mexico, Morocco and the United States. Estimates of global uranium resources associated with phosphate rocks range considerably, from 6 million to 9 million tU (cited in IAEA reports, 1965-1993 Red Books, and Haneklaus [2021]), to as high as 22 million to 24 million tU (cited in Red Book 2005, and derived from the IAEA UDEPO database; see below). These estimates use various assumptions, methodologies, cut-off grades and other considerations, such as some addressing reserves and other resources. A more comprehensive discussion about the uncertainty of phosphate resources is presented in Gabriel et al. (2013) and Haneklaus (2021).

The variation in these estimates shows that these figures should be considered as part of a general mineral inventory rather than conforming to standard categories used in reporting resources. The development of more rigorous estimates of uranium in phosphate rocks will be required if uranium market prices justify the economic extraction of uranium during the exploitation of these deposits.

Unconventional resources are not usually classified to the same degree of certainty as conventional resources (i.e. they are not identified resources), although there are notable exceptions. The majority are not currently being mined but at least some have been mined in the past, as noted above, and could be mined in the future in the right circumstances. Until demand and prices increase, however, most unconventional resources are not economically feasible sources of uranium in current market conditions.

Unconventional resources and the UDEPO database

The IAEA maintains a database of global uranium deposits, “UDEPO”. It is primarily a geological (mineral deposit) database, with little emphasis given to the economic aspects or implications of uranium ore bodies. It has several specific purposes, the primary one being to provide insights into uranium mineralisation. It is also used for the evaluation of regional-scale resource potential as well as related modelling and assessment methods.

UDEPO consists of uranium-bearing occurrences for which a resource estimate is (or was) available. They are classified into 15 main types and 50 subtypes according to the IAEA uranium deposit-type classification system (see IAEA, 2018b), several of which are considered to be largely subeconomic at the present time (these are dominated by low-grade unconventional deposit types, such as black shale deposits). For a given deposit, the maximum resource publicly reported is recorded. It is commonly an estimate calculated using the lowest cut-off grade, without any mining and processing constraints, and/or including all low-reliability mineralisation inferred. In rare cases, remaining resources or production estimates are given where they are the only known amounts available, but in general the resources given are the largest known initial resources. In addition, in some instances, a deposit in UDEPO may represent an ore body, or one of two or more mines exploiting a single larger ore body, or a mining district consisting of multiple ore bodies and mines that has not been disaggregated.

For the sake of completeness, UDEPO also contains many historic resources that do not comply with modern resource estimating procedures, or that utilise a variety of estimation techniques. Moreover, particularly in the case of unconventional resources, where formal resource estimates are rare, Secretariat estimates are given using minimal data. Secretariat estimates are also given for deposits that have not yet undergone formal ore delineation analyses, and may never be developed for economic reasons, such as low tonnages or low grades. These deposits, however, are important for predicting (modelling) the location and amount of undiscovered uranium resources at regional scales, and hence included in UDEPO.

It is important to note that the Red Book and UDEPO define "unconventional resources" somewhat differently. For the Red Book, unconventional resources are "resources from which uranium is only recoverable as a minor by-product, such as uranium associated with phosphate rocks, non-ferrous ores, porphyry copper, carbonatite, black shale and coal-lignite". For UDEPO, which is first and foremost a geological database, there is no economic connotation, thus unconventional resources are those of low to very low grade that are not or cannot be mined just for uranium. For example, with respect to deposit types, the Red Book considers resources associated with phosphate, lignite coal, black shale, polymetallic Fe-oxide breccia complex (with the exception of the Olympic Dam uranium by-product deposit in Australia), and a subtype of intrusive deposits (i.e. plutonic) to be unconventional. UDEPO considers resources associated with phosphate to be unconventional, and resources associated with lignite coal and black shale to be mostly unconventional, but with some notable exceptions to also be conventional (e.g. some "high grade" black shale deposits in Uzbekistan are considered conventional for UDEPO). Other discrepancies also exist. So, there is no simple one-to-one correspondence between unconventional resources reported in the Red Book and unconventional resources recorded in the UDEPO database.

Therefore, uranium resources recorded in UDEPO represent optimistic, maximum resource amounts that have been identified and entered into the database to date (there are certainly more deposits yet to be discovered). UDEPO should be used at an order-of-magnitude, aggregated, and global or continental scale. As such, deposit uranium resources and ore grades (where available) are provided only as ranges (e.g. 1-300 tU, 300-1 000 tU). Caution should be used when using UDEPO estimates, or making comparisons with uranium resources reported in the Red Book. Further, on an individual basis, it is not recommended to use a deposit or small groups of deposits for economic representations or comparisons.

Given these caveats above, and using the UDEPO definition of "unconventional", the latest version of UDEPO (scheduled for release in 2023), which has over 5 200 deposits, reports about 61 million tU of unconventional resources in approximately 360 deposits (that have resource amounts recorded) located in 55 countries. Conversely, using the Red Book definition of "unconventional", UDEPO reports about 57 million tU in approximately 210 deposits (that have resource amounts recorded) in 53 countries. That represents a difference of 4 million tU, or 6.5%. As indicated above, these estimates of unconventional resources derived from UDEPO should be viewed with caution. A more reliable guide for unconventional resource totals of current economic interest can be found in recent editions of the Red Book.

This edition of the Red Book includes information for countries that: 1) have been preparing to mine or are mining unconventional uranium resources, and maintain well-defined deposits as part of their conventional mineral resource inventory; 2) have well-defined unconventional uranium resources, and have firm plans for mining; 3) have nuclear power aspirations but have not yet defined sufficient domestic conventional uranium resources, and are actively exploring unconventional resources; 4) have well-defined unconventional uranium resources that may be amenable to mining; and 5) have unconventional uranium resource targets in their early exploration programmes.

Countries preparing to mine or currently mining unconventional uranium resources, and maintaining well-defined deposits as part of their conventional mineral resource inventory:

- **Australia** – Although considered an important by-product of copper and gold mining at Olympic Dam, uranium has been produced for several years in what is here considered an unconventional uranium resource. However, the multi-metal Olympic Dam deposit is exceptional in size and uranium is routinely produced along with the primary targets of the mining operation, and is thus considered conventional by Australia.
- **India** – Carbonate deposits form the largest part of India's well explored uranium resources, accounting for over 57% of recoverable RAR (more than 122 000 tU, cost range unassigned) and are considered conventional resources by India. Strata bound carbonates have provided feed for the Tummalapalle mill since 2017, but because India does not publish information on

uranium production and details of the deposits being mined, neither the grade of the deposits nor the total production from the mill are known.

- **Kazakhstan** – Although estimates are not made of Kazakhstan's unconventional uranium resources and other materials, the uranium contained in well explored phosphates and lignite coal deposits is considered a part, albeit small (<13% and <2% of the higher cost (<130 and <260 USD/kgU) recoverable RAR and IR), of the country's uranium resource base. Balausa LLP is developing by open pit the Bala-Sauskandykskoye deposit where uranium is produced as a by-product of vanadium. A very small amount of uranium-bearing ore, containing about 4 005 kgU, was mined and stockpiled during 2019-2020.

- **Russia** – Although only a small part of the country's resource endowment (<4% and <3% of the higher cost [<130 and <260 USD/kgU] RAR and IR), phosphates are considered conventional resources in Russia because uranium is the main commodity of interest.

- **South Africa** – A significant unconventional resource base in paleo-quartz-pebble conglomerates and derived tailings and coal-hosted deposits has been reported in recent Red Books, all of which could be sources of by-product uranium. Uranium is hosted primarily by coal (with minor amounts in the mudstones) in the Springbok Flats. In the 2016 edition of the Red Book, 70 775 tU in lignite and coal deposits were reported as inferred in situ conventional resources. This is a good example of a reclassification of resources from unconventional to conventional. This reclassification is subjective since there are some parts of the definition of these resource classes that are open to different interpretations. In addition, uranium production and resources from tailings is reported as conventional and in association with the paleo-quartz-pebble conglomerate deposit type.

  As reported in the 2011 edition of the Red Book, a field of manganiferous phosphate nodules was identified off the west and south-west coast of South Africa on the continental shelf. The nodules contain low grades of uranium and are currently considered uneconomic with respect to both phosphate and uranium extraction. Renewed interest in phosphate-hosted uranium deposits, however, may generate future investigation. These unconventional resources have been previously estimated to contain up to 180 000 tU.

- **Uzbekistan** – Several black shale type uranium deposits were identified during the 1960s in the Auminzatau Mountains district. Although resources of individual deposits are relatively small and low grade (0.02 to 0.13% U; averaging 0.05% U), uranium resources in well explored black shales amount to <4% and 40% respectively of the higher cost (<130 and <260 USD/kgU) RAR and IR uranium resource endowment. Black shale deposits in Uzbekistan are estimated to contain almost 33 000 tU of recoverable IR uranium resources.

  In August 2009, GoscomGeology (Uzbekistan's State Geology and Mineral Resources Committee) and the China Guangdong Nuclear Uranium Corp. (CGN-URC), set up a 50%-50% uranium exploration joint venture to focus on uranium extraction from black shale deposits in the Boztau area of the Central Kyzylkum Desert in the Navoi region, where approximately 5 500 tU resources have been reported. From 2011 to 2013, CGN-URC was to develop technology for producing uranium and vanadium from these deposits, but no activities have been reported since that time. Given recent low uranium prices, development of Uzbekistan's black shale deposits has been indefinitely delayed.

Countries with well-defined unconventional uranium resources and firm plans for mining:

- **Brazil** – The Santa Quitéria phosphate/uranium project, an INB-Brazilian fertiliser producer partnership agreement, remains under development. The deposit is estimated to contain over 50 000 tU in situ RAR available at an incremental cost of <USD 40/kgU, just under 40% of the country's well explored uranium endowment. Santa Quitéria's phosphates are also higher grade (0.08% U) than most phosphate deposits. At full production, the Santa Quitéria Project could produce close to 1 950 tU/yr.

The licensing of the Santa Quitéria phosphate/uranium project is split into a non-nuclear part, involving milling and phosphate production, and a nuclear part, involving uranium concentrate production. In 2012, the project operators applied for a construction licence that was denied in 2018. INB and its partner subsequently developed a new model for the project and a revised licence application was filed in 2020, with a decision expected in 2022. The operation is now scheduled to begin in 2024.

- **Denmark (Greenland)** – The Ilimaussaq igneous complex of South Greenland hosts the REE-U-Zn-F Kvanefjeld deposit. It is a high-tonnage, low-grade uranium-enriched layered intrusive deposit, with concentrations of around 300 ppm U (0.03% U). Uranium was planned to be mined (see below) as a by-product from a proposed open-pit mine, accounting for about 5% of total revenue from the mining. Kvanefjeld is the only uranium deposit or occurrence in Greenland with reasonably assured uranium resources. The supply cost for uranium was expected to be very low, as most of the costs were to be borne by the production of REE, the primary mining target (Kvanefjeld is considered to be one of the largest REE deposits in the world). A uranium specific supply cost of approximately USD 13/kgU (USD 5/lb U_3O_8) has been reported, which is incremental to the cost of the REE production.

  The total identified in situ reasonably assured conventional mineral resource inventory for Kvanefjeld is 102 820 tU. Additional in situ inferred mineral resources of 125 143 tU are related to the Kvanefjeld deposit. The recoverable uranium resources using the established and pilot plant tested flowsheet are approximately 50%.

  Development of mining has taken several years, in part related to issues associated with uranium mining in a jurisdiction that has never produced uranium, complicated by a previous ban on uranium mining and the need for both Greenland and Denmark to agree to all legislative and regulatory requirements for uranium mining and export. This has been further complicated by an April 2021 election in Greenland that led to a change in government that passed a new law prohibiting exploration and exploitation of uranium as of December 2021. Passage of this new law led the project developer, Greenland Minerals Ltd., to request arbitration proceedings with the governments of Greenland and Denmark concerning the impact of new legislation on its exploration licence for the Kvanefjeld REE zinc and uranium project under development in southern Greenland.

- **Finland** – A 2020 resource update from project operator Terrafame Oy estimated that in situ unconventional resources of uranium in the Talvivaara black schist-hosted Ni-Zn-Cu-Co deposit total approximately 19 400 tU at an average grade of 0.0017% U in the measured and indicated resources of 1 142 Mt, and about 25 500 tU at an average grade of 0.0017% U in the total mineral resources (measured, indicated and inferred) of 1 500 Mt.

  Between 2010 and 2015, Talvivaara Sotkamo Oy prepared for uranium recovery as a by-product from the Talvivaara deposit in Sotkamo, eastern Finland. The Talvivaara Ni-Zn-Cu-Co deposit is hosted by metamorphosed black shales in the Kainuu Schist Belt. It is a low-grade, large-tonnage deposit averaging 0.26 wt% Ni, 0.53 wt% Zn, 0.14 wt% Cu, 0.02 wt% Co and 0.0017 wt% U.

  In 2012, the Finnish government granted a uranium extraction licence to Talvivaara Sotkamo Oy in accordance with the nuclear energy legislation. In 2013, however, the Supreme Administrative Court returned the licence to the Finnish government for reassessment due to several changes in the operations after the licensing decision, including a corporate reorganisation. Talvivaara Sotkamo Oy then filed for bankruptcy in 2014. The state-owned company Terrafame Oy acquired the operations and assets of Talvivaara Sotkamo Oy from its bankruptcy estate in 2015, and as of 1 January 2021, was carrying on the mining operations in Sotkamo.

  In 2017, Terrafame Oy applied to the Finnish government for a licence to recover uranium as a by-product at Terrafame's mine in Sotkamo, in accordance with the nuclear energy legislation. In February 2020, the Finnish government granted a uranium extraction licence to Terrafame. However, this licence was appealed to the Supreme Administrative Court. In June 2021, the Supreme Administrative Court confirmed the uranium extraction licence that had been previously granted by the government. The mine site in Sotkamo currently includes an almost fully completed uranium solvent extraction plant from the time of Terrafame's predecessor, Talvivaara Sotkamo Oy. Terrafame expects to start uranium production in Sotkamo in 2024, principally to remove uranium impurities from the Ni-Co sulphide concentrate before refining, once the economic feasibility of uranium recovery has been established and the investment decision has been finalised, along with final plant design, project implementation, deployment and start-up of the uranium solvent extraction plant.

Countries with nuclear power aspirations that have not yet defined sufficient conventional uranium resources, and are actively exploring unconventional resources:

- **Jordan** – In 1982, a feasibility study for uranium extraction from phosphoric acid was completed by a German engineering company on behalf of the Jordan Fertiliser Industry Company, leading to the subsequent purchase by the Jordan Phosphate Mines Company. One of the extraction processes evaluated was originally found to be economically feasible, but as uranium prices dropped in the 1990s, the process became uneconomic, and construction of an extraction plant was deferred.

  After SNC-Lavalin performed a technological and economic feasibility study for the recovery of uranium from the phosphoric acid produced at the Aqaba Fertilizer Complex, the economics of the project improved and JUMCO conducted research to develop optimised extraction parameters, with promising results. Jordan's phosphate deposits are estimated to contain some 100 000 tU in situ but, due to limited exploration, are not yet considered classified resources.

- **Malawi** – In the Kanyika Niobium Project held by Globe Metals, uranium is an important by-product in the complex niobium and tantalum ore in a pegmatite quartz vein, hosted in Proterozoic felsic schists. Niobium and tantalum products would be produced with uranium as by-product. As of December 2012, total resources amount to 68.3 Mt of ore at an average grade of 0.28% Nb_2O_5, 0.0135% Ta_2O_5 and 0.0067% U (4 550 tU). Globe Metals & Mining submitted an environmental impact assessment (EIA) for the Kanyika Niobium Project for public review in May 2012. In January 2019, Globe Metals announced that it had finalised the feasibility study, including revision of the mineral resource estimates, mining, metallurgical studies, processing, engineering design and infrastructural support. It obtained updated capital and operating cost estimates and updated its financial model. However, Globe Metals is not yet in a position to finalise the financial model and the key outcomes of the project, due to the current uncertainty associated with the status of the mining law in Malawi, and to the status of negotiations between Globe Metals and the government on the Development Agreement.

- **Saudi Arabia** – An exploration programme was initiated in 2017 to develop domestic mineral resources in line with Saudi Arabia's Vision 2030 goal to have a mining sector that contributes to the national economy and to develop sufficient domestic uranium resources to fuel its planned nuclear power programme. As a result of this exploration programme, uranium deposits and prospects have been reported as in situ inferred unconventional resources, including uranium resources associated with Nb, Zr, REE, Ta + Th, in peralkaline granite and pegmatite in the Ghurayyah and Jabal Sayid areas, and uranium associated with phosphate horizons. Total in situ unconventional uranium resources amount to 77 731 tU, including 63 171 tU associated with the intrusive plutonic deposit type and 14 560 tU associated with the phosphorite type.

  Phosphorite deposits in the Sirhan-Turayf shelf in northern Saudi Arabia form part of the large North African Middle East Tethyan phosphate province, which stretches from Morocco to Iraq. The Thaniyat phosphorite member at the base of Jalamid Formation of late Cretaceous (Campanian) to Paleocene age, was deposited in a shallow marine shelf to intertidal zone. The uraniferous phosphorite layer extends continuously within a target area of about 70 km^2 and has an average thickness of 1.8 m, with an average density of 2.0 g/cm^3. The IR in situ resource is estimated to total 14 551 tU and the current resource is severely uneconomic.

Countries with well-defined unconventional uranium resources that may be amenable to mining:

- **Central African Republic** – While the Bakouma uranium deposit is associated with phosphates and the country does not report unconventional resources, it is classified as a conventional deposit because of relatively high uranium grades (0.15-0.30% U). In its 2020 Annual Report, Orano (the current owner of the project) reported the results of a new resource evaluation that estimates IR in situ resources of 36 475 tU available at <USD 260/kgU at an average grade of 0.20% U. The start-up of the Bakouma pilot project was initially planned for 2010, with open-pit mining initially producing 1 200 tU/yr and 2 000 tU/yr at full capacity. The uranium mining project was, however, suspended at the end of 2011 for one to two years due to low uranium prices and the need for further research on the metallurgy.

- **Chile** – The production of copper oxide minerals has quadrupled in Chile over the last decade and the copper industry, particularly large-scale mining, has strategic (sub-economic) uranium potential in the large volumes of copper oxide leaching solutions that could be recovered. These resources are assigned an in situ potential of 1 000 tU. However, no background studies have been performed to confirm these estimates, either as mining resources or in terms of the volumes of solutions treated annually.

  Over the last decade, private firms, both domestic and foreign, have explored 12 "exotic copper" deposits in Chile, essentially paleochannels filled with gravel, mineralised with copper silicates, oxides and sulphates primarily as a result of the natural leaching of porphyry copper deposits. These mineralised bodies contain variable uranium contents ranging between 7 to 116 ppm (0.007 to 0.016% U). The leaching solutions in the plants that treat these copper oxide minerals contain up to 10 ppm U that is technically recoverable using ion-exchange resins at a likely production cost of over USD 80/kgU. A pilot-level trial, conducted between 1976 and 1979, obtained about 0.5 tU from copper-rich solutions containing 10 to 15 ppm U (0.001 to 0.0015% U).

  Beyond this trial, there has been no experience in recovering uranium from phosphorites in Chile. The only deposit currently being worked is Bahía Inglesa in Region III (Atacama), which produces a solid phosphate concentrate used directly as fertiliser. In 2001, Compañía Minera de Fosfatos Naturales Ltda. (Bifox Ltda.) began producing phosphoric acid from this deposit, opening the potential of recovering uranium from the acid.

  Identified unconventional recoverable RAR amount to 1 169 tU (<USD 260/kgU), including 415 tU in phosphates, while undiscovered unconventional resources are estimated to total 5 458 tU.

Countries with unconventional uranium resource targets in their early exploration programmes:

- **Ecuador** – Early exploration activities included the examination of the Puyango sedimentary deposit (V, Zn, U, Cu, Pb), where tabular-shaped uranium mineralisation is hosted by the Early Cretaceous Puyango Unit, which consists of black limestone, bituminous limestone and calcareous sandstone. This deposit may be considered a potential source of U, where this metal may be recovered as minor co- or by-product to other metals. However, no assessment of uranium resources and processing technologies has been carried out. Further south in the Alamor-Lancones basin, the Maastrichtian Cazaderos Formation consisting of medium grained sandstones, black shales and siltstones could also host uranium occurrences.

- **Egypt** – Phosphate deposits represent one of the more promising unconventional uranium resources, with estimates suggesting that they amount to about 700 million tonnes, with uranium content ranging between 50 ppm and 200 ppm (0.005-0.02% U). However, no reliable estimate of the uranium resources in Egyptian phosphate ores has been made since 2008, when it was reported in the 2009 Red Book that up to 42 000 tU may be contained in Egyptian phosphates.

Black sands are considered the second most important unconventional source of uranium in Egypt. Radioactive monazite comprises one of the black sand ore minerals and is estimated to contain about 6 million tonnes of heavy minerals. In one area, the monazite contains up to 0.5% U and 6% Th, as well as rare earth elements (REE).

From 1999 to 2003, Egypt worked on the development of a semi-pilot plant for the extraction of uranium from phosphoric acid, but unexpected technical problems delayed uranium production. The project was suspended due to challenges related to the low uranium content of the phosphoric acid and difficulties in the extraction cycle. The semi-pilot plant for the purification of phosphoric acid has since been converted to produce phosphoric acid for agricultural, food and other domestic purposes, and the country has returned to the development of conventional sources of uranium.

- **Indonesia** – The uranium resource potential in the Bangka and Belitung areas is comprised of placer deposits of monazite within a tin deposit. Monazite, a uranium/thorium phosphate mineral, was deposited in the alluvium and has mostly accumulated as a tailings by-product material of tin mining. The total resource from deposits in Bangka and Belitung islands amounts to 25 236 tU. In Singkep, the uranium potential is in lateritic soil, with a resource of 1 100 tU. In Semelangan (West Kalimantan), uranium is present in bauxite lateritic deposits, with resources of 624 tU. In Katingan (Central Kalimantan), monazite is present as a by-product material of zircon mining, with resources of 485 tU. Total unconventional monazite resources are therefore estimated to amount to 27 445 tU, with about 100 000 tU contained in Indonesian phosphate deposits. However, no effort has yet been made to develop uranium extraction technologies from these unconventional deposits.
- **Mexico** – The San Juan de la Costa phosphorite deposit is estimated to contain significant uranium resources, but no systematic evaluation of the contained uranium or the optimal processing method to extract the uranium has been conducted.
- **Nepal** – Early exploration efforts led to the determination that the most important phosphate occurrence in Nepal is the Baitadi Carbonate Formation in the Lesser Himalaya of Far East Nepal. The phosphate-rich horizon of middle Proterozoic age (1 200 to 1 000 Ma), confined to the stromatolitic Massive Cherty Dolomite member among seven lithological members, extends laterally over more than 25 km with thickness varying from a few metres to 18 m. The P_2O_5 content varies from 10 to 32 wt%. Neither the average phosphate nor uranium content of the occurrence has been determined, prohibiting the evaluation of the economic potential of the Baitadi Formation.

  Coal occurrences in Nepal are found in four stratigraphic horizons: Quaternary lignite of the Kathmandu valley, Siwalik coal of the Sub Himalayas/Churia Range, Eocene coal of the Western and mid-Western Nepal, and Gondwana coal. Although the uranium content of these horizons is unknown, the lignite horizon in the Kathmandu valley may have significant uranium contents owing to the presence of uranium showings in the gneissic muscovite-tourmaline granites and pegmatites north of Kathmandu city. Only the Quaternary lignite of the Kathmandu valley and the Eocene coal has been mined for domestic needs. The resources from the Quaternary lignite and the Eocene are quite limited and even if they were relatively rich in U, its recovery will not be of economic interest. However, due to the presence of U-rich orthogneisses surrounding the Kathmandu depression, it is likely that these lignites are significantly enriched in U.

  Black shales also occur in various parts of Nepal, but they are generally metamorphosed and deformed, and their uranium content is not known. The probability of having significant uranium resources in this type of lithology is limited given the present state of knowledge.
- **Peru** – Unconventional resources in Peru account for a minimum of 41 600 tU in situ, which include phosphates (16 000 tU), granites with high uranium content (20 000 tU) and hydrothermal deposits (5 600 tU).

In 2010, the Vale company (formerly Vale do Rio Doce) of Brazil started exploitation of the Bayóvar phosphate deposit through its local subsidiary, Miski Mayo SRL. Before the start of the operation the company planned for the possibility of uranium recovery during phosphate production, but these plans have not yet been implemented.

- **Sri Lanka** – Sri Lanka reported in the Red Book 2020 that a current focus of its early work on national fissile material development was to identify radioactive mineralisation in the country with an emphasis on the extraction of uranium from unconventional sources. Through IAEA technical co-operation projects, a substantial amount of technical assistance was provided to Sri Lanka for the discovery of economic uranium and thorium mineralisation, but no resource determinations have been reported.

  Varying concentrations of heavy mineral sands (ilmenite, rutile, garnet, zircon, monazite) occur in the beach sands of the country. However, only certain locations have concentrations that are deemed sufficient for potential economic exploitation. From 2016 to 2019, four new areas of anomalous radioactivity were identified in the coastal stretch from Talaimannar to Galle. Fieldwork from Talaimannar to Kudiramalai was completed in 2017 and continued to Puttalam to the end of 2019. Follow-up work is anticipated. Monazite-rich beach sand placer deposits are known to occur along the coastal stretch covering the Aluthgama-Beruwala-Induruwa southwest sector and the Kudiramalai northwest sector of the island. Notable amounts of thorianite-rich sands are reported in beach sands in the Beruwala-Induruwa areas. Monazite and thorianite sands are reported to occur in lesser concentrations within the Pulmuddai, Thirukkovil and Galle mineral sand occurrences. Urano-thorianite deposits also occur in river placers (southwest). Monazite concentrations of 0.3-1% are known to occur in approximately 75 million tonnes of inland REE deposits (northwest). Monazite-bearing beach mineral samples collected from the east coast Pulmoddai Deposit were processed to separate monazite and analyse for trace elements by AEB laboratories. The analysis revealed values up to 23% Ce in monazite. Geophysical surveys for near offshore minerals in southwest Sri Lanka identified an estimated volume of sediments of 170 million tonnes in 11 potential basins to a depth of 2 metres. Monazite concentrations of up to 1.1% were estimated based on gamma-ray spectrometry analysis.

- **Viet Nam** – Uranium exploration activities associated with rare earth element ores (Dong Pao bastnaesites, Namxe bastnaesite, YenPhu xenotime and beach sand monazite, etc.) are being conducted, but resource determinations stemming from these efforts have yet to be reported. Research focused on the recovery of thorium and uranium from rare earth concentrates has been undertaken, and a continuous counter-current extraction process for the simultaneous recovery of thorium and uranium from the Yen Phu rare earth concentrate leach solutions was developed by the Institute for Technology of Radioactive and Rare Elements. Results show that the extraction method is suitable for the recovery of thorium and uranium from rare earth concentrate with thorium and uranium purities of greater than 99%.

In summary, unconventional uranium deposits remain an important part of the global uranium endowment and in some countries mining is already underway or planned. However, for many of the unconventional deposits discussed above, sufficient exploration has not yet been conducted to develop high confidence resource estimates and costs of production remain too high for commercial production in today's market. Moreover, licensing for mining some of these deposits has proven challenging, particularly in jurisdictions that have not recently or have never mined uranium, since licensing involves both radiological (nuclear) and non-radiological components. Development of mines that extract uranium as a co- or by-product also depends on the primary mining target(s), markets, and the fortunes of the companies conducting the mining, which may have little experience with uranium. However, if uranium demand and prices rise to near historic highs, or if demand for REE, lithium and other co-occurring targets of interest rise even further, unconventional uranium resources could once again contribute more significant quantities of uranium to the global market.

Seawater

The world's oceans have long been regarded as a possible source of uranium because of the large amount of contained uranium (over 4 billion tU) and its inexhaustible nature. However, because seawater contains such low concentrations of uranium (3-4 parts per billion), developing a cost-effective method of extraction remains a challenge.

Research on uranium recovery from seawater was carried out initially from the 1950s to the 1980s in Germany, Italy, the United Kingdom and the United States. From 1981 to 1988, the Agency for Natural Resources and Energy, the Ministry of International Trade and Industry, and the Metal Mining Agency of Japan teamed up to operate an experimental marine uranium adsorption plant based on TiO_2 adsorbents.

A renewal of interest in the last 15 years led to a special issue of the Journal of Industrial and Engineering Chemical Research devoted to the recovery of uranium from seawater (ACS, 2016). One of the leading methods considered for extracting uranium from seawater at that time involved infusing fibres made of polyethylene, a common plastic, with amidoxime, a chemical group pioneered by Japanese researchers in the 1980s that attracts uranium dioxide and binds it to the fibre (Kuo et al., 2016; Abney et al., 2017). Researchers at the Pacific Northwest National Laboratory and LCW Supercritical Technologies subsequently produced five grams of yellowcake using this method (PNNL, 2018). This and other developments are estimated to have reduced the cost of uranium extraction from seawater by a factor of three to four based on laboratory experience (CNA, 2016; PNNL, 2016).

Researchers at Stanford University subsequently developed an electrochemical method to capture uranium from seawater, demonstrating a nine-fold increase in uranium capacity, a four-fold faster rate of uranium accumulation, and favourable reusability compared to the best adsorbent materials developed for the same purpose (Abate, 2017; Liu et al., 2017). The application of carbon nanotube technology to extract uranium from seawater was also investigated, owing to the high surface area of the material for adsorption and its rapid ion transport capability (Ahmad et al., 2020; Zhao et al., 2019). However, finding a simple method to prepare the new carbon structure proved challenging.

To overcome bio-fouling on wet sorbent surfaces, a guanidine and amidoxime polypropylene non-woven fabric was developed that showed improved selectivity and anti-fouling performance, thereby accelerating the rate of uranium sorption (Zhang et al., 2018). Poly phenylacetylene conductive chains incorporated into the porous adsorbent channels as a pathway for ion transportation by electrically driven motility achieved a record uptake capacity of uranium in a 90-day test using natural seawater (Wang et al., 2020), although low uranium seawater concentrations and interfering ions reduced overall efficiency. "Pre-enriching" uranium content in seawater was experimentally achieved through development of a glycerine cross-linked graphene oxide-based membrane that effectively captured co-existing ions (K^+, Na^+, Ca^{2+} and Mg^{2+}) while rejecting approximately 100% of the uranium (Chu et al., 2022).

A reusable bioinspired film with extremely small pores that adsorbs uranyl ions rapidly through hierarchical (increasingly smaller) porous channels increased adsorption capacity up to 20 times (Zhang, 2021). Importantly, the film can be cleaned with HCl for reuse (Sparkes, 2021). Calcium carbonate mesospheres synthesised by nanoemulsion to produce interconnected mesospheres of high surface area showed high rates of uranium adsorption that was easily recovered after adsorption by dissolution of the mesospheres in acid (Dongsheng et al., 2022). Inspired by the high uranium content in natural marine carapaces, tests using the crystalline calcium carbonate in ground crab carapace achieved high uranium extraction capacities (Feng et. al., 2022).

These and other techniques have been recently investigated in what has become an active area of research, particularly in China. While each resulted in an improvement in both the capture and recovery of uranium from seawater, it is important to note that these are laboratory tests only. Development of an industrial scale method of extracting uranium from seawater, even with the bench scale improvements recently demonstrated, will need to overcome several challenges, including the vast amounts of seawater that would need to be processed, ecological concerns potentially arising from such a process, and production costs that remain significantly above market prices. However, should an economical method be developed, it would be the ultimate low-impact method of producing uranium, bolstering the low-carbon standing of nuclear power and dispensing with any concerns of uranium shortages, should nuclear power experience rapid growth.

Uranium exploration

Non-domestic

Only four countries (China, France, Japan and Russia) have reported non-domestic exploration and development expenditures since 2008, and this was reduced to three countries in this edition as China did not report (Table 1.14). Non-domestic expenditures are a subset of domestic (i.e. within country) expenditures as the totals reported on a country-by-country basis are a total of expenditures from both domestic and foreign sources within each country. The recent trend in non-domestic exploration and development expenditures is depicted in Figure 1.4. During this reporting period, non-domestic expenditures declined from USD 142.9 million in 2017 to USD 75.7 million in 2018, USD 56.8 million in 2019 and USD 39.2 million in 2020. They are expected to increase to USD 70.7 million in 2021 (preliminary data). In this edition, non-domestic exploration and development expenditures reported by France and Japan declined from 2019 to 2021, likely due to poor market conditions, whereas expenditures by Russia increased considerably in 2020 and 2021 as exploration and mine development activities continued in Namibia, Kazakhstan and Tanzania, raising non-domestic expenditures by Russia to levels not seen since 2012.

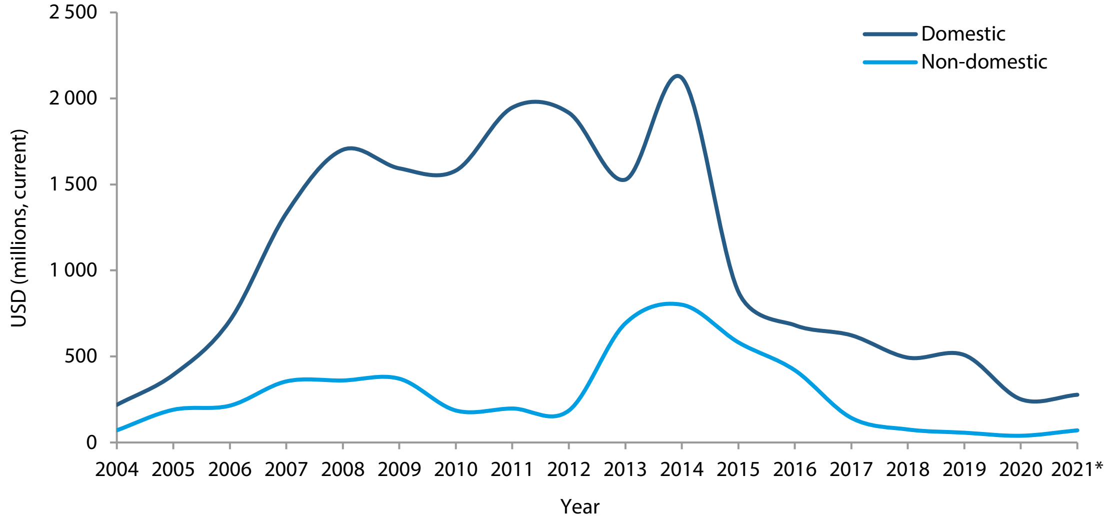
Table 1.14. **Non-domestic uranium exploration and development expenditures***

(as of 1 January 2021, USD thousands in year of expenditures, for countries listed)

Country	Pre-2014	2014	2015	2016	2017	2018	2019	2020	2021 (preliminary)
Australia	NA	NA	NA	NA	NA	NA	NA	NA	NA
Belgium	4 500	0	0	0	0	0	0	0	0
Canada	355 644	NA	NA	NA	NA	NA	NA	NA	NA
China	1 443 500	762 980	526 310	378 010	108 110	41 480	23 580	NA	NA
France	1 514 680	27 600	34 866	30 736	30 765	30 240	26 400	24 920	22 140
Germany	403 158	0	0	0	0	0	0	0	0
Japan	443 423	5 465	3 922	5 089	2 245	2 239	3 228	3 133	2 601
Korea	NA	NA	NA	NA	NA	NA	NA	NA	NA
Russia	NA	4 900	17 100	6 100	1 800	1 700	3 610	11 100	45 930
Spain	20 400	0	0	0	0	0	0	0	0
Switzerland	29 679	0	0	0	0	0	0	0	0
United Kingdom	61 263	0	0	0	0	0	0	0	0
United States	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total	4 276 247	800 945	582 198	419 935	142 920	75 659	56 818	39 153	70 671

* Domestic exploration and development expenditures represent the total expenditure from domestic and foreign sources within each country. Expenditures abroad are thus a subset of domestic expenditures. Unless otherwise noted, all expenditures made by majority government-owned companies and their subsidiaries are considered expenditures by government. NA = Data not available.

Figure 1.4. **Trends in exploration and development expenditures**



* 2021 values are estimates.

Several countries do not report non-domestic expenditures or have not reported these expenditures recently, and thus the data are incomplete. Private companies in Canada and Australia are known to make non-domestic investments and are likely leading investors in foreign uranium exploration and development activities, but no information has been reported by these governments for the past several years.

Domestic

Twenty-one countries reported domestic exploration and mine development expenditures for this edition (Table 1.15). The totals reported are on a country-by-country basis and represent the total expenditures from both domestic and foreign sources within each country. The recent trend in domestic exploration and development expenditures is depicted in Figure 1.4. As in the previous report, the overall picture is one of declining expenditures since 2015 with total expenditures dropping by 71% from over USD 876.5 million in 2015 to USD 251.3 million in 2020. However, expenditures were expected to increase slightly to USD 277.4 million in 2021, despite China, one of the leading countries in exploration and development expenditures in recent years, not reporting expenses in 2020 or 2021. From 2015 to 2020, decreased expenditures in many countries were related to persistently low uranium prices that slowed exploration and mine development projects.

Of the 19 countries reporting exploration and mine development expenditures in the period 2019 through 2021 (seven of these reporting only two years or less), the total over this three-year period amounts to just over USD 1 billion. Canada (USD 505.5 million, or 50.0% of the total) led the way, followed by India (USD 179.2 million, 17.7%), China (USD 154 million or 15.2%; with only 2019 expenditures reported), Kazakhstan (USD 42 million, 4.2%), Namibia (USD 36.2 million, 3.6%), Russia (USD 32.4 million, 3.2%), Türkiye (USD 21.5 million, 2.1%; with 2021 expenditures not reported), Australia (USD 18.6 million, 1.8%), Saudi Arabia (USD 12.8 million, 1.3%; reporting uranium exploration expenditures for the first time), and Jordan (USD 8.8 million, 0.9%). Expenditures in Canada alone exceeded the total spending of the eight countries ranked second to ninth (India, China, Kazakhstan, Namibia, Russia, Türkiye, Australia and Saudi Arabia), demonstrating once again that Canada (mainly the Athabasca Basin) remains the prime destination for uranium exploration.

Table 1.15. **Domestic (industry and government) uranium exploration and development expenditures***

(as of 1 January 2021, USD thousands in year of expenditures, for countries listed)

Country	Pre-2014	2014	2015	2016	2017	2018	2019	2020	2021 (preliminary)
Algeria	NA	0	0	0	0	0	0	0	0
Argentina	115 653	4 244	5 880	4 142	5 092	2 376	1 496	1 089	4 166
Australia	1 630 331	37 124	33 665	17 295	15 115	9 044	7 138	4 589	6 870
Bangladesh	453	NA	NA	NA	NA	6	6	7	8
Belgium	2 487	0	0	0	0	0	0	0	0
Bolivia	9 343	NA	NA	NA	NA	NA	NA	NA	NA
Botswana**	12 629	NA	NA	NA	NA	NA	NA	NA	NA
Brazil	189 732	0	224	1 348	574	0	0	0	0
Cameroon	1 282	NA	NA	NA	NA	NA	NA	NA	NA
Canada[(a)]	6 765 387	525 677	397 249	319 785	253 435	198 496	210 687	140 876	153 906
Central African Rep.	21 800	NA	NA	NA	NA	NA	NA	NA	NA
Chile	9 618	NA	NA	NA	NA	NA	NA	NA	NA
China	740 000	197 000	152 000	128 000	125 000	120 000	154 000	NA	NA
Colombia	25 946	NA	NA	NA	NA	NA	NA	NA	NA
Costa Rica	364	NA	NA	NA	NA	NA	NA	NA	NA
Cuba	972	NA	NA	NA	NA	NA	NA	NA	NA
Czech Republic [(b)]	315 200	1 327	633	514	17	9	197	284	289
Denmark/Greenland	4 210	2 195	NA	NA	NA	NA	NA	NA	NA
Ecuador	1 945	NA	NA	NA	NA	NA	NA	NA	NA
Egypt	117 271	NA	NA	28	28	84	90	186	254
Ethiopia	22	NA	NA	NA	NA	NA	NA	NA	NA
Finland	124 474	1 753	0	0	0	0	0	0	0
France	907 240	0	0	0	0	0	0	0	0
Gabon	102 443	NA	NA	NA	NA	NA	NA	NA	NA
Germany [(c)]	2 002 789	0	0	0	0	0	0	0	0
Ghana	90	NA	NA	NA	NA	NA	NA	NA	NA
Greece	17 547	NA	NA	NA	NA	NA	NA	NA	NA
Guatemala	610	NA	NA	NA	NA	NA	NA	NA	NA
Hungary	4 051	NA	NA	NA	NA	NA	NA	NA	NA
India	647 648	43 983	49 858	52 156	63 732	60 852	66 165	47 805	65 268
Indonesia	18 038	100	464	233	121	81	246	42	25
Iran, Islamic Rep. of	267 680	50 179	6 276	17 320	39 221	13 567	8	NA	NA
Ireland	6 200	NA	NA	NA	NA	NA	NA	NA	NA
Italy	75 060	0	0	0	0	0	0	0	0
Jamaica	30	NA	NA	NA	NA	NA	NA	NA	NA
Japan	16 697	0	0	0	0	0	0	0	0
Jordan	34 859	3 820	3 697	2 886	3 531	4 831	3 531	2 444	2 825
Kazakhstan	529 115	34 676	60 934	23 935	36 620	37 252	18 779	13 367	9 911
Korea, Republic of	17 866	NA	NA	NA	NA	NA	NA	NA	NA
Lesotho	21	NA	NA	NA	NA	NA	NA	NA	NA
Madagascar	5 239	NA	NA	13	24	NA	23	NA	NA
Malawi	NA	NA	NA	NA	NA	NA	NA	NA	NA
Malaysia	10 478	NA	NA	NA	NA	NA	NA	NA	NA
Mali	56 693	1 516	774	387	390	354	298	30	NA
Mexico[(d)]	30 761	106	93	66	886	1 204	871	NA	NA

Continued on next page.

Table 1.15. **Domestic (industry and government) uranium exploration and development expenditures*** *(cont'd)*

(as of 1 January 2021, USD thousands in year of expenditures, for countries listed)

Country	Pre-2014	2014	2015	2016	2017	2018	2019	2020	2021 (preliminary)
Mongolia	177 537	15 436	7 816	6 600	7 172	4 857	158	71	74
Morocco	2 752	NA	NA	NA	NA	NA	NA	NA	NA
Namibia	344 182	1 041 434	9 962	8 253	3 310	3 718	5 960	11 068	19 208
Niger(e)	1 048 927	NA	NA	4 504	322	6 937	2 912	2 527	NA
Nigeria	6 950	NA	NA	NA	NA	NA	NA	NA	NA
Norway	3 180	0	0	0	0	0	0	0	0
Paraguay	26 360	690	0	0	NA	NA	250	250	250
Peru	4 776	NA	NA	NA	NA	NA	NA	NA	NA
Philippines	3 492	NA	NA	NA	NA	NA	NA	NA	NA
Poland	NA	229	0	NA	NA	NA	NA	NA	NA
Portugal	17 637	NA	NA	NA	NA	NA	NA	NA	NA
Romania	10 060	NA	NA	NA	NA	NA	NA	NA	NA
Russia	977 005	39 917	17 581	18 907	9 980	8 336	8 782	13 808	9 804
Rwanda	1 505	0	0	NA	NA	NA	NA	NA	NA
Saudi Arabia(f)	0	0	0	0	9 000	16 000	9 000	3 000	849
Slovak Republic	NA	408	NA	NA	NA	0	0	0	0
Slovenia(g)	1 581	0	0	0	0	0	0	0	0
Somalia	10 000	NA	NA	NA	NA	NA	NA	NA	NA
South Africa(h)	297 517	1 655	5 164	NA	NA	NA	NA	NA	NA
Spain	202 790	5 400	9 106	1 160	1 180	908	893	285	417
Sri Lanka	43	NA	NA	NA	NA	NA	NA	NA	NA
Sudan	200	NA	NA	NA	NA	NA	NA	NA	NA
Sweden	47 900	NA	NA	NA	NA	NA	NA	NA	NA
Switzerland	3 359	0	0	0	0	0	0	0	0
Syria	1 151	NA	NA	NA	NA	NA	NA	NA	NA
Tanzania	NA	NA	NA	NA	NA	NA	NA	NA	NA
Thailand	11 299	NA	NA	NA	NA	NA	NA	NA	NA
Türkiye	30 441	4 875	6 842	223	768	2 987	14 245	7 288	NA
Ukraine	57 508	1 337	689	484	1 111	800	2 235	1 762	3 312
United Kingdom	3 815	0	0	0	0	0	0	0	0
United States(i)	4 062 813	102 100	105 000	71 900	44 300	NA	NA	NA	NA
Uruguay	231	NA	NA	NA	NA	NA	NA	NA	NA
USSR	3 692 350	0	0	0	0	0	0	0	0
Uzbekistan	269 715	NA	NA	NA	NA	NA	NA	NA	NA
Viet Nam	15 373	1 875	2 610	1 794	1 540	NA	NA	NA	NA
Zambia(j)	9 732	NA	NA	NA	710	607	502	536	NA
Zimbabwe	6 902	NA	NA	NA	NA	NA	NA	NA	NA
Total***	26 189 357	2 119 056	876 517	681 933	623 179	493 305	508 472	251 313	277 438

* Domestic exploration and development expenditures represent the total expenditure from both domestic and foreign sources in each country for the year. ** Secretariat estimate. *** Updated totals from 2012 on with corrected expenditures: Mexico (2012-2016) and Australia (2016). NA = Data not available. (a) Development expenses only reported in 2021. (b) Includes USD 312 560 expended in Czechoslovakia (pre-1996). (c) Includes USD 1 905 920, spent in GDR between 1946 and 1990. (d) Government exploration expenditures only. (e) Pan African and Global Atomic exploration spending only in 2018 and 2019, Global Atomic exploration spending only in 2020. (f) Secretariat estimate of annual spending from total spending of USD 37 000 000 reported in Country Report. (g) Includes expenditures in other parts of the former Yugoslavia. (h) Includes expenditures for both uranium and gold in the Witwatersrand Basin until 2012. (i) Includes reclamation and restoration expenditures from 2004 to 2012. Reclamation expenditures amounted to USD 49.1 million, 62.4 million, 41.7 million, 46.3 million in 2008, 2009, 2010, 2011, 2012, respectively. (j) Non-government industry expenditures between 2011 and 2013, 2017 and 2018.

Declining expenditures were reported from 2019 to 2021 in Indonesia (USD 246 000 to USD 25 000), Kazakhstan (USD 19 million to USD 10 million) and Saudi Arabia (USD 9 million to USD 849 000). Generally increasing expenditures over this same period were reported by the Czech Republic (USD 197 000 to USD 289 000), Egypt (USD 90 000 to USD 254 000) and Namibia (USD 6 million to USD 19.2 million). Exploration and mine development expenditures were relatively steady from 2019 to 2021 in Australia (~ USD 6.2 million), Canada (~USD 170 million), India (~USD 60 million), Jordan (~USD 2.9 million), Russia (~USD 11 million), Spain (~USD 500 000) and Ukraine (~USD 2.5 million). Finland reported exploration expenditures for 2014; however, from 2015 onwards, there is no data for Finland as it is not possible to separate uranium exploration expenditures from the total reported for gold exploration, in which uranium is a potential co- or by-product. Due to very low values and confidentiality concerns, no expenditures were reported for the United States from 2018 to 2021; expenditures have been in dramatic decline since 2012 when exploration and mine development expenditures amounted to USD 166 million, compared to USD 44.3 million in 2017, a decrease of 73%.

Global exploration and mine development expenditures were expected to increase in 2021 to USD 277.4 million, a 10% increase compared to 2020, although the increase is likely greater since 2021 expenditures were not reported for key countries such as China, Niger, Türkiye and Zambia. Increases in expenditure from 2020 to 2021 are, however, expected in important uranium producing countries, such as Australia, Canada, India, Namibia and Ukraine. For the 2019 to 2021 period, of the countries that reported exploration and development expenditures separately, Canada and Kazakhstan reported greater exploration than mine development expenditures (except for Kazakhstan in 2021), whereas Ukraine reported greater mine development than exploration expenditures.

For the first time in this edition of the Red Book, a table summarising recent global drilling activities is included (although not comprehensive nor complete). Fifteen countries reported drilling activities, although nine reported only partially (i.e. some years or entities involved in exploration and/or mine development activities were not reported). Data from four countries are included from the previous edition of the Red Book to round out data for 2018 and 2019 in order to give a more complete picture (Table 1.16). For the countries reporting data, total drilling declined by 42% from 2018 (2 633 128 m) to 2021 (1 100 934 m), although the number of countries providing data declined from 15 to 10 over these same years. For the countries reporting exploration and development drilling meterage separately, development drilling accounted for 19% of total drilling in 2018, 15% in 2019, 28% in 2020 and 47% in 2021, although the number of countries reporting development drilling declined from 5 in 2018 to 3 in 2021. Note that the separate totals for exploration and development do not always add up to the total metres drilled as the United States does not report this information separately and drilling data for India and Russia were not separated into exploration and development. Also noteworthy is that drilling data for Canada were not available in 2020 and 2021 and that the United States has not provided data since 2017, owing to very low values and confidentiality concerns. Despite these gaps, the reported global drilling effort has not only declined since the last reporting period, but it has also been in decline since 2012, when 17 countries reported drilling that totalled 5 368 268 m in the 2016 edition of the Red Book.

In terms of exploration drilling distance from 2018 to 2021, most countries reported irregular trends as COVID-19 work restrictions disrupted drilling plans and several countries did not report drilling distance in each year. Of the countries that reported drilling for each year, Namibia and Egypt were the only countries reporting upward trends in exploration drilling, although drilling in Namibia was significantly greater than that reported for Egypt. Kazakhstan and Ukraine reported declining drilling distance while India reported relatively steady drilling length in each year. In contrast, Argentina and Russia reported variable drilling distance.

Of the countries reporting exploration and development drilling data for all four years (2018-2021), Kazakhstan accounted for between 27%-65% of global drilling distance, India between 10%-25%, Namibia 1%-8%, Ukraine 1%-8%, Argentina and Egypt <1% (note that 2018 data from the previous edition of this publication were included for Namibia and Ukraine). Percentages for these countries were generally highest in 2020 and 2021 since Canada and China did not report exploration drilling distance in these years. In 2018 and 2019, China accounted for about 22% and

33% respectively of global exploration drilling, Kazakhstan 35% and 27% and Canada 12% in both years. In 2020 and 2021, Kazakhstan led with 58% and 65% shares without China and Canada reporting drilling distance in these two years. Kazakhstan reported its largest exploration drilling distance in 2018 at almost 930 000 m, India in 2021 at over 279 000 m, Namibia in 2021 at over 82 000 m, and Ukraine in 2018 at over 212 000 m.

Table 1.16. **Exploration and development drilling data for select countries**

(as of 1 January 2021, for 2018-2021, metres)

Country	2018			2019			2020			2021 (expected)		
	Exploration	Develop.	Total	Exploration	Develop.	Total	Exploration	Develop.	Total	Exploration	Develop.	Total
Argentina	2 373	0	2 373	654	0	654	385	0	385	4 115	0	4 115
Canada*	260 640	52 734	313 374	188 954	65 156	254 110	NA	NA	NA	NA	NA	NA
China*	580 000	NA	580 000	720 000	NA	720 000	NA	NA	NA	NA	NA	NA
Egypt	1 500	0	1 500	2 000	0	2 000	1 550	0	1 550	3 100	0	3 100
India	250 808	0	250 808	278 732	0	278 732	195 308	0	195 308	279 250	0	279 250
Indonesia	0	0	0	425	0	425	0	0	0	0	0	0
Iran*	1 883	8 252	10 135	4 757	4 326	9 083	NA	NA	NA	NA	NA	NA
Kazakhstan	712 250	217 718	929 968	362 136	230 647	592 783	433 462	358 957	792 419	205 015	505 522	710 537
Mauritania[1]	NA	0	NA	7 900*	0	7 900*	NA	NA	NA	NA	NA	NA
Mexico*	2 582	0	2 582	NA	NA	0	NA	NA	0	NA	NA	0
Mongolia	14 222*	0	14 222*	1 100	0	1 100	0	0	0	0	0	0
Namibia	18 756*	14 511*	33 267*	32 957	16 600	49 557	47 423	5 319	52 742	73 240	9 417	82 657
Niger[2]	NA	NA	21 390	NA	NA	11 863	NA	NA	NA	NA	NA	NA
Paraguay[3]	0	0	0	330	0	330	330	0	330	330	0	330
Russia	115 210	NA	115 210	35 879	NA	35 879	114 653	NA	114 653	6 400	NA	6 400
Türkiye	110 012*	0	110 012*	198 613*	0	198 613*	193 329	0	193 329	NA	NA	NA
Saudi Arabia	35 360	0	35 360	17 700	0	17 700	0	0	0	0	0	0
Spain	0	0	0	0	0	0	0	0	0	3 350	0	3 350
Ukraine	7 410*	205 517*	212 927*	601	10 524	11 125	0	12 740	12 740	1 485	9 710	11 195
US	W	W	W	W	W	W	W	W	W	W	W	W
Totals	2 113 006	498 732	2 633 128	1 852 738	327 253	2 191 854	986 440	377 016	1 363 456	576 285	524 649	1 100 934

* From Red Book 2020. 1. Tirus drilling only. 2. 2018 Orano and GAC only; 2019 Orano only. 3. Total drilling reported for multiple years divided into equal yearly totals. NA = Data not available. W = Data withheld to avoid disclosure of individual company data.

Only four countries reported development drilling for all four years (2018-2021) in this edition: Egypt, Kazakhstan, Namibia and Ukraine. Kazakhstan dominated development drilling length in all four years, from 44% in 2018 to 70% in 2019, 95% and 96% in 2020 and 2021, respectively. Namibia and Ukraine accounted for between 2% and 5% of total global development drilling in each year, with the exception of Ukraine reporting 41% of total development drilling in 2018, while Egypt's development drilling amounted to <1% in each year between 2018 and 2021.

Trenching data, reported only by Argentina (2018 and 2021 only), Egypt, Iran (2018 and 2019 only), Jordan (2018 only) and Saudi Arabia (2018 and 2019 only), totalled over 10 500 m (1 851 trenches) in 2018, 2 229 m (65 trenches) in 2019 and 330 m (14 trenches) in 2020 (Egypt only), with 600 m (40 trenches) expected in 2021 (Argentina and Egypt only). In 2018, Iran and Jordan accounted for over 90% of the global total trenching length. In 2019, Iran accounted for 67% of the global total. Egypt accounted for 100% and 83% of the trenching distance reported in 2020 and 2021 while Argentina accounted for 17% of the 600 m that were expected to be excavated in 2021.

Current activities and recent developments

North America

The North American region continued to dominate reported uranium exploration and mine development activities, accounting for about 40% of total global expenditures in 2018 and 2019, then rising to about 55% of total expenditures in 2020 and 2021 as expenditures in China were not reported for these years. This dominance continues despite the United States not reporting exploration and mine development expenditures since 2017 and Mexico not reporting since 2019.

Canada, despite the global trend of declining exploration and development expenditures, has maintained higher than average expenditures and in 2020 accounted for 56% of the world total for countries reporting this data. Total Canadian uranium exploration and development expenditures in 2019 amounted to USD 210.7 million, a 6% increase from 2018. This ended a series of expenditure declines since 2013 (USD 845.1 million) but was short-lived, as expenditures slid to USD 140.9 million in 2020, with USD 153.9 million expected in 2021. Uranium development expenditures declined from CAD 253 million in 2016 to CAD 114 million in 2019 and CAD 105 million in 2020, comprising about 60% to 46% of total expenditures in these years, respectively. This decrease and the 45% decrease in exploration expenditures (from CAD 170 million in 2018 to CAD 88 million in 2020) is primarily due to work-related COVID-19 pandemic restrictions and low uranium prices.

Box 1.1. **SABRE mining method**

SABRE (Surface Access Borehole Resource Extraction) is an innovative and scalable mining method that can allow for the exploitation of relatively small high-grade orebodies that are either too small or too deep to be mined economically by open-pit and (or) underground mining methods. It is a surface-based, non-human-entry method that uses a single high-pressure water jet placed at the bottom of a drill hole to excavate a mining cavity. An access hole is drilled to an orebody and a high-pressure fluid injection tool is then lowered down the hole on a specialised mining string to disaggregate the ore material and form a subsurface cavity. The ore material is optionally ground to a desired size by a drill bit and is air-lifted as a slurry through production tubing to the surface for further processing. The injection and grinding tools are optimally part of an integrated bottom-hole assembly at the lowermost end of a drill string. The bottom-hole assembly also includes surveying equipment to measure the cavity dimensions at intervals during excavation, thus allowing fluid injection adjustments to achieve a desired cavity geometry and dimension. Adjacent cavities can be excavated as long as the previous one has been backfilled.

Beginning as a mining equipment invention initiative in 2004, SABRE was developed by Orano Canada Inc. in joint-venture partnership with Denison Mines Corp. as a technique for selectively recovering high-value ore from shallow deposits in the Athabasca Basin. In 2021, a five-year field-testing programme was completed at the McClean Lake property in Saskatchewan, Canada. Four mining cavities were successfully excavated to produce approximately 1 500 tonnes of high-value ore ranging in grade from 4% to 11% U_3O_8 (3.4% to 9.3% U). SABRE was able to achieve key test programme operating objectives, such as targets for cavity diameter, rates of recovery, and mine production rates, with no safety, environmental, or radiological incidents.

Due to its less intrusive nature and potentially smaller surface footprint, SABRE can significantly reduce the environmental impact of this mining method, when compared to conventional mining methods. Reduced water usage and power consumption can also contribute to potential reductions in greenhouse gas emissions. Additionally, as a non-entry mining method, it has significant safety and radiological benefits.

Despite poor market conditions, Canada's high grade uranium deposits remain the prime target for uranium exploration. Recently discovered large high grade uranium deposits include Phoenix/Gryphon and Heldeth Túé (Denison Mines Inc.), Triple R (Fission Uranium Corp.), Arrow (Next-Gen Energy Corp.) and Fox Lake (Cameco Corp.). While work-related COVID-19 pandemic restrictions have limited activity at many of these projects, Denison continues technological testing and is conducting an environmental assessment of a proposal to mine the Phoenix deposit by ISR, the first proposed use of this method for unconformity-type uranium deposits. Denison's Heldeth Túé project is also slated to be mined by ISR.

In the United States, the total expenditures for land, exploration, drilling, production and reclamation decreased to USD 108.8 million in 2018, down 11% from USD 122.6 million in 2017 and notably lower than the 2016 total of USD 169.9 million. The trend of decreased expenditures that began in 2013 continued to the point that since 2018 most information is being withheld by the United States Energy Information Administration to avoid disclosure of individual company data due to the limited number of companies reporting. Publicly available information, however, even if not officially reported, indicates that investment in the exploration sector has continued to decrease significantly during this period. The overall decrease in reported expenditures (except exploration expenditures in 2017) was primarily the result of a depressed uranium market and a global oversupply of uranium during a lengthy period.

In Mexico, after several years of modest expenditures, total exploration and development expenditures increased from USD 0.66 million in 2016 to USD 1.2 million in 2018, as the government invested in the re-evaluation of resource declarations for 53 previously discovered uranium deposits, drilling 5 164 m in 47 holes through 2017 and 2018. Results showed that previous work did not meet international standards of evaluation and the main exploration effort was to be focused on Santiago Papasquiaro, where anomalies and evidence of surface and underground uranium minerals have been defined. No exploration and development expenditures were officially reported by Mexico for 2019, but according to publicly available information from the Mexican Geological Survey, 2019 expenditures were approximately USD 871 000. Subsequently, exploration activities slowed down, no drilling campaigns were carried out, and no exploration and mine development expenditures were reported for 2020 and 2021.

Central and South America

Uranium exploration and mine development expenditures in the Central and South American region accounted for <2% of reported global expenditures from 2018 to 2021, with ongoing activities in a number of countries despite sharply reduced expenditures in Brazil, the only country that had produced uranium in this region in recent years.

In Argentina, the continued investment in uranium exploration aligns with the 2006 government policy of reactivating the national nuclear energy programme. Reported domestic exploration expenditures by government in 2018 amounted to 26.9 million Argentine pesos (ARS), increasing to ARS 31.8 million in 2019, then declining to ARS 27.4 million in 2020, with ARS 63 million expected in 2021 (expenditures in local currency are considered a more reliable guide due to the extreme Argentinean currency fluctuations in recent years). Expenditures by private exploration companies amounted to ARS 39 million, ARS 32.3 million and ARS 48.8 million in 2018, 2019 and 2020 respectively, but are expected to increase significantly to ARS 287 million in 2021. However, because there is no requirement for private industry to report exploration expenditures, the amounts reported may not reflect all expenditures in the sector.

From 2017 to 2019, exploration activities carried out by the government slowed down and no drilling was carried out. Activities were focused on field work for geological and radiometric reviews, geophysical surveys, sampling for geochemical analysis and environmental studies. Government exploration activities in Argentina were expected to intensify in the second half of 2021, including a 1 200 m drilling programme in the Neuquén basin, but this was postponed until 2022.

Of those uranium deposits managed by the CNEA (the National Atomic Energy Commission), the most relevant in the assessment/exploration stage is Cerro Solo in Chubut Province. Work to define the hydrometallurgical extraction line of uranium and molybdenum minerals and laboratory-scale sample testing was completed, but further up-scale testing was postponed. Since 2018, only environmental monitoring has been carried out at the site since hydrological, palaeontological, socio-economic, air quality, flora and fauna, pedological and archaeological studies have been completed. Radiometric/radiological and natural acidic drainage surveys are being developed in compliance with provincial regulations.

Sophia Energy S.A., UrAmerica Ltd, Blue Sky Uranium Corp., U3O8 Corp. and Consolidated Uranium Inc. reported exploration-related activities during the 2017-2021 period. Sophia Energy S.A. continued exploration of its mining properties at the Laguna Sirven deposit in Santa Cruz Province, including completion of a 600 km^2 radiometric airborne survey of the entire project. In December 2019, Sophia Energy S.A. received approval from the provincial government to perform an intensive two-year advanced exploration programme focused on resource assessment, but the COVID-19 pandemic caused exploration activities to be put on hold since early 2021.

In 2019, Blue Sky Uranium Corp. announced the first preliminary economic assessment (PEA) for the Ivana deposit (Amarillo Grande project), as well as an updated inferred in situ resource estimate, including 8 730 tU at 0.031% U and 2 920 tV at 0.011% V. Exploration in 2019 continued to focus on expanding the mineralisation proximal to the Ivana deposit. A drilling programme was launched in Q1 2020, immediately halted due to the COVID-19 pandemic, and then resumed in Q1 2021.

In June 2021, International Consolidated Uranium Inc. announced that it had chosen to exercise its option to purchase the Laguna Salada project (Chubut province) from U3O8 Corp. In December 2021, this acquisition was completed and, although the Laguna Salada project has been in care and maintenance since 2014, it is expected that exploration activities will be resumed in the short term.

Exploration drilling by private companies totalled 2 373 m (236 holes) in 2018, 654 m (88 holes) in 2019, 385 m (8 holes) in 2020, before increasing to 4 115 m (80 holes) in 2021. Exploration trenching was also reported in 2018 (60 m in 39 trenches) and 2021 (100 m in 20 trenches).

In Brazil, no exploration and mine development expenditures were reported from 2018 to 2021. In late 2020, a reassessment of resources in several deposits in the provinces of Lagoa Real and the Santa Quitéria deposit was initiated, with results expected in 2022. Efforts have been devoted to making the transition from open pit to underground mining of the Cachoeira deposit, developing open-pit mining of the Engenho deposit and expanding the Lagoa Real production centre.

Chile did not report exploration and development expenditures for this edition and, given the lack of updates on projects in northern Chile's iron-oxide copper-gold belt, with potential for copper, gold, silver and uranium, activity has likely continued at a reduced pace since 2016.

In Ecuador, between 2019 and 2021, the Geological and Energy Research Institute (IIGE) of Ecuador, assisted by the IAEA through the Undersecretariat of Nuclear Control, Investigations and Application´s liaison, updated and reviewed historical information on uranium exploration in the country, with the objective of taking up research carried out years ago by the National Polytechnic School and the Ecuadorian Atomic Energy Commission (CEEA). Despite these surveys and background research, the Mining Regulatory and Control Agency (ARCOM) has not reported any private or state concessions in its mining portfolio related to uranium exploration in recent years.

In 2020, the Private Technical University of Loja (UTPL) carried out a geochemical survey in the Chirimoyo and Guineo micro-basins in the Puyango area, finding anomalies of V, U and Zn related to black limestones, bituminous limestones and calcareous shales of marine origin. This study confirmed the radiometric anomalies previously identified by the National Polytechnic School and the CEEA in the 1970s and 1980s.

Since U3O8 Corp. left Guyana in 2012, there has been no significant exploration, but the Guyana Geology and Mines Commission (GGMC) continues to conduct annual geochemical projects to map the country's mineral potential. In recent years, GGMC data from Permission for Geological and Geographical Survey (PGGS) Areas for both light and heavy rare earth elements has shown that uranium concentrations are higher than other elements, ranging from more than 2.7 to 296 ppm (0.0003% U to 0.03% U). GGMC was expecting to continue carrying out geochemical survey projects in Guyana's interior, beginning in September 2021.

The government of Paraguay did not respond to the Red Book questionnaire for this edition, although exploration was carried out by Uranium Energy Corporation (UEC) from 2019 to 2021 in the Coronel Oviedo area. Several radon emmanometry surveys and drilling exploration totalling approximately 1 000 m were conducted, with total operating expenditures amounting to USD 750 000. UEC has reported an exploration target at Coronel Oviedo ranging from 8 900 to 21 500 tU at grades between 0.034 and 0.044% U and that the uranium-bearing unit has aquifer characteristics suitable for ISL.

For Peru, no exploration and development expenditures were reported in this edition, and the industry is not required to report expenditures to the government. In 2021, American Lithium Corp. acquired Plateau Energy Metals and its projects in the Macusani district and announced drilling plans (12 000 m; 70 holes) for the Macusani project to expand existing uranium resources and identify new deposits. The permitting process has been initiated, including development of an environmental impact assessment and community access agreements. Drilling is expected to start once an exploration permit is granted.

European Union

Uranium-related exploration and mine development activities in the European Union accounted for <0.5% of total reported global expenditures from 2018 through 2021, as the main activities continued to be focused on remediation of closed uranium mines. Mine development activities continued in Denmark (Greenland), Hungary and Spain, but new legislation jeopardises projects in Denmark (Greenland), and in July of 2021, Spain's nuclear regulator blocked Berkeley Energia's planned uranium mine over safety concerns.

In the Czech Republic, exploration and development expenditures dropped from USD 514 000 in 2016 to USD 17 000 in 2017 and USD 9 000 in 2018, before increasing to USD 197 000 in 2019, USD 284 000 in 2020 and USD 289 000 in 2021. After closure of the Rozná mine in 2017, exploration activities have been focused on the conservation and processing of previously collected exploration data from Czech uranium deposits. Advanced processing of the exploration data and building of an exploration database will continue in the coming years. In 2019 and 2020, activities included analysis and evaluation of rock samples, geological documentation, developing a feasibility study and final reports, as well as archiving data. No drilling data has been reported in the Czech Republic since 2016.

Denmark (Greenland) reported total expenditures of between USD 1.5 million and 3 million for all commodities from 2016 to 2019, but the portion spent on uranium is not possible to separate. No expenditure figures for 2020 and 2021 were reported, and no drilling data was reported for the entire five-year period. Since 2007, Greenland Minerals Limited (GML; prior to 2018, Greenland Minerals and Energy Ltd) has conducted rare earth element (U-Zn) exploration activities in the Kvanefjeld area, South Greenland, including drilling of 57 710 m of core. A mining/exploitation licence application was submitted in July 2019, including updated environmental and social impact assessments together with a navigational safety investigation study. However, an April 2021 election in Greenland led to a change in government that passed a new law prohibiting exploration and exploitation of uranium as of December 2021. Passage of this new law prompted GML to request arbitration proceedings with the governments of Greenland and Denmark concerning the impact of this new legislation on its exploration licence for the Kvanefjeld REE, zinc and uranium project under development in southern Greenland.

In Finland, no exploration expenditures or drilling data exclusively for uranium have been reported since 2014. However, uranium may be included in some active gold exploration permits.

In France, although no domestic uranium exploration and mine development activities have been carried out since 1999, majority government-owned Orano (formerly Areva) and its subsidiaries remain active abroad. As of 2020, Orano S.A. has been working outside France, focusing on discovery of exploitable resources in Canada, Gabon, Kazakhstan, Mongolia, Namibia and Niger. In Canada, Kazakhstan and Niger, Orano is also involved in uranium mining operations. In addition, as a non-operator, Orano holds shares in several mining operations and research projects in different countries. In 2020, Orano started exploration in Uzbekistan. Total non-domestic exploration expenditures remained relatively steady from 2017 to 2018 at about USD 30 million per year, before declining by 17% to around USD 25 million in 2019 and 2020.

The government of Hungary did not report any exploration or mine development expenditures for this edition. The non-governmental mine development project, which started in 2007 with a focus on the Mecsek deposit and surroundings, is still in the environmental licensing phase. The Environmental Impact Study submitted at the end of 2017 is expected to be modified regarding the planned production rate, following some legal actions and discussions with the environmental authority. If a licence is obtained, a mining property could be established and likely merged with the existing, historic mining properties in the area.

For Poland, no exploration and development expenditure data were reported, although there are some prospective indications of uranium and currently some small prospects amenable for the discovery of uranium that could potentially be economically exploited.

In Portugal there has been no exploration or exploitation of uranium since 2001, although there are unexploited uranium deposits located in the southern part of the country. However, no future production centres are planned, and rehabilitation and remediation (environment and safety) are the only activities being undertaken.

In the Slovak Republic, exploration in Kuriskova associated with the Košice uranium deposit, initiated in 2011 by Ludovika Energy Ltd (a subsidiary of European Uranium Resources), came to an end in 2015 when exploration licences were not renewed by the government. Several protests and lawsuits over the allocation of exploration areas followed, as well as political discussions to ban uranium mining and exploration in the country, and no new uranium exploration licences have been issued in the Slovak Republic since.

In Slovenia, expenditures on uranium exploration ended in 1990, and there are no recent or ongoing uranium exploration activities in the country. In 1992, the final closure and subsequent decommissioning of the Žirovski Vrh mine and mill complex began with the production facility being dismantled. After finishing the remediation, the remaining disposal sites and the mine water effluents were put under long-term environmental surveillance. A hydrometallurgical tailings disposal site and a waste rock disposal site associated with this facility, are undergoing environmental remediation, with the disposal site for hydrometallurgical tailings in its final stage, and with the critical factor being the stability of the site. All remediation work was finished on the mine waste pile site, and in 2015, long-term environmental surveillance began.

Spain reported around USD 1 million in 2017 and 2018 in exploration and mine development expenditures by industry, declining to USD 893 000 in 2019 and USD 285 000 in 2020, with an increase to USD 417 000 expected in 2021. No industry exploration drilling was reported from 2018 to 2020, but 3 350 m (13 holes) of exploration drilling was expected in 2021. This reflects a shift by Berkeley Minera España S.L.U. from exploration to licensing of its proposal to mine uranium by open pit in Salamanca province. However, Spain's Climate Change Law of May 2021, which aims to ensure the nation's compliance with the objectives of the Paris Agreement and the associated energy transition. It includes a section regarding uranium mining and milling facilities in Spain. No new permits to exploit radioactive mineral deposits will be admitted after the law comes into force. In July 2021, the Spanish Nuclear Safety Council issued a negative report on the construction licence application for Berkeley's proposed processing plant. The report is mandatory, and when negative or regarding the conditions imposed, it is binding for action to be taken by the Ministry for the Ecological Transition and the Demographic Challenge (MITECO), who are in charge of granting construction licenses. Consequently, MITECO rejected Berkeley Energia's authorisation to build a uranium processing plant at the company's Salamanca project in western Spain.

On 16 May 2018, the Parliament of Sweden passed an amendment to the Environmental Code banning uranium exploration and mining in the country. Prior to this, most exploration activity was related to the potential of alum (black) shale, where uranium could be recovered as a by-product along with other co-products such as molybdenum, vanadium, nickel, zinc and petroleum products. The Australian company Aura Energy Ltd, having worked for several years developing the Häggån Project for uranium and vanadium mining, lodged a claim against the Swedish government in November 2019 for compensation of financial losses resulting from the 2018 ban on uranium exploration and mining. Although no input was received from Sweden for this edition of the Red Book, it has been reported (Casey, 2022) that Aura Energy is appealing to the Swedish government to develop the Häggån Project to address security of supply for energy and battery metals, following Vattenfall's decision to suspend orders of uranium and nuclear fuel from Russia until further notice owing to the current geopolitical situation (Vattenfall, 2022).

In previous reports, countries such as Poland and the Slovak Republic were either interested in or issuing permits to explore for and develop domestic uranium deposits for mining. Neither Poland nor the Slovak Republic, or any other country in the European Union, reported uranium exploration and mine development expenses for this edition, except for those outlined above. In February 2018, it was reported that the Supreme Court of the Slovak Republic supported the Environment Ministry in not extending an exploration licence for uranium held by Ludovika Energy.

Europe (non-EU)

Uranium exploration and mine development expenditures in non-EU countries in Europe accounted for 2.5% to 10% of total reported global expenditures in 2018 through 2021, led by exploration and mine development activities in Russia and Ukraine, supplemented by ongoing exploration in Türkiye.

In Russia, exploration of identified deposits is carried out by the subsidiary uranium mining enterprises of JSC Atomredmetzoloto (ARMZ), which is a part of the Russian State Atomic Energy Corporation Rosatom. The main exploration activities in 2019 and 2020 were concentrated on the Dobrovolnoye deposit (Dalur mine). A significant increase in investment from 2019 to 2020 (USD 1.8 million to USD 6.7 million) is associated with the development of exploration drilling at the Dobrovolnoye deposit, with completion planned for 2023. The Priargunsky production centre continued limited exploration focused on identifying uranium resources on the flanks of the deposits currently being mined by drilling boreholes from the underground mine workings.

Box 1.2. **Smart ISL Site Digital Mining System**

The "Smart ISL Site" digital mining system was developed by the ARMZ Uranium Holding Company and the Seversk Institute of Technology, and implemented at the Dalur and Khiagda ISL operations in the Kurgan Region and Republic of Buryatia in Russia, respectively. The system includes digital technologies for the management of uranium production based on automatic data collection and remote control of wellfield units, comprehensive analysis of all geological and operational data, and geological, hydrological and technical simulations.

The Smart ISL Site system is operated from a central control complex. It monitors and manages hydrodynamic processes to provide uniform leaching of wellfield units, simulates movement of groundwater in each cell and mining block, and takes into account their mutual influence on one other. The system optimises hydrodynamic conditions, automatically adjusts optimum well productivity, and identifies wells in need of repair and restoration.

Smart ISL Site improves working conditions, increases labour productivity, ensures prompt receipt and processing of operational data, and provides efficient technical solutions for ISL process optimisation. It improves the leaching process by enhancing the rate and reducing the time of uranium extraction, as well as reducing reagent consumption, resulting in significant savings in operational costs.

Domestic exploration and mine development expenditures in Russia increased from USD 8 million to 13 million from 2018 to 2020, with development expenditures increasing from 18% in 2020 to 68% of total expenditures in 2021.

From 2018 to 2020, Russia, through Uranium One (owned by Rosatom), carried out exploration and pilot test work for uranium at joint ventures in Kazakhstan, work in Tanzania to prepare for the development of the Mkuju River uranium project, and exploration in Namibia.

In Kazakhstan, six uranium mines jointly owned by Uranium One are in commercial operation. In 2020, exploration in the expanded geological allotment of the Zarechnoye deposit was completed and additional resources were identified to extend the life of the mine. In 2021, a new exploration programme was launched at the Kharasan mine to convert defined resources into more reliable categories.

Box 1.3. **Innovations at Kazatomprom JSC Uranium Mining Operations**

The national atomic company Kazatomprom continues its research aimed at the associated extraction of rare and rare earth metals from productive solutions of uranium obtained by in situ recovery (ISR) extraction method.

Scandium: Research work has been carried out to explore the possibility of obtaining scandium-containing concentrates from mother liquors of uranium sorption and to optimise the process. The possibility of obtaining non-radioactive scandium oxide has been confirmed. Work is underway on the application of nanofiltration technology to concentrate the productive solution and increase the efficiency of obtaining scandium oxide from the mother liquors of uranium ISL operations.

Rhenium: During the processing of the productive solution of ISL, rhenium along with uranium is extracted and concentrated into an ion-exchange resin, which can serve as a source for obtaining rhenium. The technique has been developed and tested on an enlarged laboratory-scale technology for the production of ammonium perrhenate. The results showed that it is feasible to extract rhenium. Kazatomprom is working on the manufacture of a mobile plant to produce a crude rhenium concentrate.

Vanadium: A project is being implemented to assess the possibility of obtaining vanadium from sorption mother liquors during uranium mining at the Zarechnoye deposit.

In Tanzania, Mantra Resources (purchased by ARMZ in 2011) completed a major exploration programme at the Mkuju River deposit in 2016. During 2017-2019, further development was suspended due to unfavourable market conditions. In 2020, a decision was made to build a pilot processing plant during 2021-2022 and to proceed with pilot open-pit mining from 2023 to 2025.

In Namibia, Uranium One, through its subsidiary Headspring Investments Pty., conducted an intensive drilling exploration programme in 2019 and 2020. As a result, a new sandstone-type uranium deposit (Wings) was discovered with JORC compliant resources amounting to RAR of 14 700 tU and IR of 9 900 tU, with an exploration potential of 40 000 tU. Based on 2020 results, resources are potentially amenable for development by ISL, and a pre-feasibility study completed in 2021 confirmed positive economics for exploitation by ISL. The 2021 exploration programme includes further drilling aimed at identifying additional resources and preparing for an ISL pilot test.

In Türkiye, government exploration expenditures increased from USD 223 000 in 2016 to USD 3.0 million in 2018, rising to USD 14.2 million in 2019 before falling to USD 7.3 million in 2020, with expenditure figures not available for 2021. Exploration drilling amounted to just over 198 600 m (484 holes) in 2019 and 193 300 m (576 holes) in 2020, the only two years reported. No development expenditures were reported. Efforts were mainly focused on exploration of granite, acidic igneous and sedimentary rocks in Edirne, Kırklareli and Tekirdağ provinces. In 2020, Çanakkale, Nevşehir, Yozgat, Giresun, Manisa and Aydın provinces were explored for radioactive raw materials and drilling was conducted in Nevşehir, Çanakkale, Giresun and Aydın provinces. In 2021, a drilling programme to confirm previous work and develop resource estimates at the Manisa-Köprübaşı exploration site was undertaken.

In early 2019, Westwater Resources Inc. reported that the Turkish government had cancelled all exploration and operating licences held by Adur in June 2018 (Adur was Westwater's Turkish subsidiary, Adur Madencilik Limited Sirketi). Adur and its predecessors had been developing the Temrezli and Şefaatli projects, carrying out drilling, testing and studies to move the projects towards production. The issue remains the subject of an arbitration tribunal as Westwater seeks compensation for its investments, with a formal ruling on the case expected in the second half of 2022 (Westwater Resources, 2022).

In Ukraine, exploration and development expenditures totalled USD 800 000 in 2018, USD 2.2 million in 2019, USD 1.7 million in 2020 and USD 3.3 million in 2021. Development expenditures accounted for 90%, 96% and 92% of total expenditures respectively over the 2019-2021 period (with most of the investments in each year made by industry), as mine development was accelerated to meet the government target of fulfilling all domestic uranium requirements with local production by 2030. During the 2019 to 2021 reporting period, a total of over 32 974 m of drilling (1 873 holes) was conducted, all by the government, with the majority (>87% each year) for development. SE Kirovgeology focused on analytical work of existing geological data to identify areas perspective for uranium exploration.

Africa

Uranium exploration and mine development expenditures in Africa accounted for about 2% of total reported global expenditures in 2018 and 2019, rising to 6% in 2020 and 7% in 2021. Although COVID-19 restrictions reduced or delayed activities in several countries, work on the development of new mines continued in Botswana, Mali, Mauritania, Namibia, Niger, Tanzania and Zambia, along with associated exploration activities in these countries and Egypt.

In Algeria, the Agence du Service Géologique de l'Algérie, in collaboration with the United States Geological Survey, conducted preliminary prospecting (reconnaissance-level) for undiscovered mineral resources (diamond, Au, PGE-Cr, Cu-Ni-PGE-Cr, Mo-Cu and uranium) related to granites, calcretes, and alkaline rocks in the Eglab Region of the Reguibat Paleoproterozoic shield in southwestern Algeria during 2017 and 2018. For granite-hosted (shear zone), calcrete-hosted and alkaline rock-hosted deposit types, it was determined that the potential for economic uranium mineralisation was low, with no significant resources identified. No uranium prospecting or mine development work was carried out between January 2019 and January 2021, largely due to the COVID-19 pandemic.

Algeria moved to regulate activities related to the research, production and peaceful use of nuclear energy with the adoption of Law No. 19-05 on 17 July 2019, leading to the creation of the National Authority for Nuclear Safety and Security under the supervision of the Prime Minister by executive decree (No 21-148 of 20 April 2021). This independent administrative authority, which has legal authority and financial autonomy, is the competent authority charged with drafting legislation and regulations relating to nuclear activities and guides of good practice to ensure the safety and security of operations, and to ensure their application. Its prerogatives also include the issuance of authorisations and licences, control of installations, approval of training programmes, approval and management of emergency plans, and co-operation with international and regional organisations. Pending the establishment of the independent authority, the Atomic Energy Commission (COMENA) continues to exercise its prerogatives.

In Botswana, no exploration and mine development expenditures were reported. However, Australian based A-Cap Resources (now A-Cap Energy Limited), after conducting research to optimise mining and attending to the requirements of the Letlhakane Uranium Project's mining licence, shifted its efforts to requesting extensions on the commencement of the pre-construction and construction period specified in the Letlhakane mining licence due to low uranium market prices and COVID-19 pandemic work restrictions in 2019. In September 2021, the government amended the licence at A-Cap's request to specify that the construction period will start by 30 September 2024.

In the Central African Republic, following the attack at the Bakouma project site in 2012 that led to the suspension of all activities, field uranium exploration and mine development work has not been undertaken. However, in its 2020 Annual Report, Orano outlined the results of a new resource evaluation that shows IR in situ resources amounting to 36 475 tU at an average grade of 0.20 %U in the <USD 260 cost category. This is a downgrade of resources reported in previous editions of the Red Book, where Bakouma resources were reported as 42 200 tU RAR in situ in the <USD 260 cost category. While the Bakouma uranium deposit is associated with phosphates, which are typically reported as unconventional resources, it is classified as a conventional deposit because of the relatively high (0.15-0.30% U) uranium grade.

The last time the Democratic Republic of Congo (DRC) reported exploration activities to the Red Book was in 1988 (at that time the DRC was known as Zaire). Recently, the IAEA has been providing support for the identification and evaluation of uranium and other radioactive resources in the Katanga province in the DRC through the Technical Co-operation programme entitled, "Strengthening National Capacities for the Assessment of Uranium Resources and Other Radioactive Minerals and for the Regulation of Associated Mining Activities". This programme began in 2018 and continued through 2020.

Egypt reported government exploration and mine development expenditures of USD 84 000 in 2018 and USD 90 000 in 2019, before increasing significantly to USD 186 000 and USD 254 000 in 2020 and 2021 respectively, as the Egyptian Nuclear Materials Authority (NMA) focused efforts on the exploration of four prospects in the Eastern Desert and South Sinai. These activities involved exploratory trenching and shallow drilling programmes and were supported by geophysical and geochemical surveys following subsurface extensions of the formations hosting uranium mineralisation. They resulted in significantly increased prognosticated resource estimates. Mine development expenditures comprised 33% of total expenditures from 2018 to 2021 as pilot production facilities planned for 2025 at Abu Rusheid (where uranium occurrences are associated with REEs) and El Sella as well as established facilities at Gattar and Abu Zenima continue to investigate uranium recovery through heap and vat leaching, and beginning in 2019, by ion exchange. Exploratory trenching amounted to 1 310 m (46 trenches) and drilling totalled 9 450 m (394 holes) between 2018 and 2021.

Egypt has had ongoing support for over two decades in developing uranium exploration and production capacities through several IAEA Technical Co-operation projects. The most recent include "Enhancing Regional Capabilities for a Sustainable Uranium Mining Industry" and "Supporting a Feasibility Study for Uranium and Rare-Earth Element Recovery from Unconventional Resources", both of which began in 2018; "Supporting Uranium, Thorium and Rare Metal Evaluation, Production and Purification from Conventional Resources" and "Supporting Uranium Recovery from Solid Radioactive Waste Produced in the Radioisotope Production Facility", both of which began in 2020; and "Enhancing Regional Capabilities for Sustainable Uranium Exploration and Mining (AFRA)" and "Supporting Feasibility Study for Uranium, Thorium and Rare Metals Recovery from Conventional Resources", both of which began in 2022.

For Malawi, no exploration and mine development expenses were reported, as activities ground to a halt when the government imposed a moratorium in 2015 on applications and grants for all mining and exploration tenements until a new cadastral system and a new minerals act is introduced. On 14 December 2018, the National Parliament of Malawi passed new legislation (Mines and Minerals Bill 2018) to update and replace the current, outdated legislation. The Mines and Minerals Bill was assented to by State President Arthur Peter Mutharika on 25 January and gazetted on 15 February 2019. As of June 2020, the mines and minerals regulations for the new legislation had been finalised and were awaiting gazetting.

While no exploration activities since 2015 were reported, an ownership change occurred to the country's only uranium mine (Kayelekera, now idled). On 13 March 2020, Paladin completed the sale of its 85% interest in Paladin (Africa) Ltd to Lotus Resources (65%) and Lily Resources Pty Ltd (20%). Lotus, formerly Hylea Metals Ltd, holds 76.5% of the shares in Lily with Kayelekera

Resources Pty Ltd holding 23.5%, giving Kayelekera Resources Pty Ltd an indirect 20% interest in the Kayelekera project. The remaining 15% of shares in Paladin (Africa) Ltd are held by the Malawi government. Paladin is to receive a 3.5% royalty based on revenues derived from future production at Kayelekera, capped at AUD 5 million.

In Mali, reported private sector exploration and mine development expenditures of USD 390 000 in 2017 and USD 354 000 in 2018, before declining to USD 298 000 in 2019 and USD 30 000 in 2020 as a rebellion in the north-eastern part of the country limited activities to the western regions of the country. As of 20 December 2021, four uranium exploration permits had been granted to two exploration companies in Mali. In 2019, ASTER images of the Falea area were interpreted for the identification of new exploration targets and in May and June 2020, soil and termitaria sampling were completed. The geochemical results highlighted significant gold anomalies, in addition to already known U, Cu and Ag anomalies in the Falea project area. During the fourth quarter of 2020, GoviEx conducted a core sampling and geophysics programme, which identified a significant correlation between the Birimian geology, the fault structures and the geophysical chargeability anomalies in relation to gold mineralisation. No uranium exploration drilling was completed in 2020. In January 2021, GoviEx announced a 6 000 m air core drilling programme to test the gold potential associated with soil anomalies.

In Mauritania, no exploration and development expenditures were reported, although private sector activity to advance mine development continues, notably by Australia's Aura Energy at the Tiris (Reguibat) project. On 29 July 2019, Aura released the results of the Definitive Feasibility Study, which confirmed that the Tiris Uranium Project is both a low cost and a low operating cost development. The project is designed to support an open-pit mine, a 1.25 million tonne ore processing plant and supporting infrastructure. The uranium mineralisation lies largely within 3 to 5 m of the surface in a relatively soft, free digging material containing patchy calcrete. Based on trenching and metallurgical test work to date, the mineralisation does not require blasting before mining or crushing prior to beneficiation.

In 2021, Aura released the results of new resource estimates of the Tiris East deposits, resulting in a 2 080 tU increase in resources and a new JORC compliant resource estimate including the Sadi South Zone. Based on an 85 ppm U cut-off (0.0085% U), global in situ Tiris project resources total 7 499 tU in the measured and indicated categories, and 14 308 tU in the inferred category. In July 2021, Aura commenced Stage 2 exploration, with key results of this work expected to include detailed results of several approaches being considered to lower operating costs, completion of a net zero emission study, water drilling results building on 2019 findings and the potential positive impact on the Tiris project operating cost from vanadium by-product recovery. The Tiris project is 85% owned by Tiris Resources SA, a subsidiary of Aura Energy Ltd, and 15% by the Mauritanian government through its agency Société Mauritanienne des Hydrocarbures et de Patrimoine Minier (SMH-PM).

Support in the uranium production cycle has been provided through an IAEA Technical Co-operation project, "Establishing an Effective Monitoring Mechanism for Environmental Protection related to Uranium and Mining Activities". The project began in 2014 and continued through 2017. The specific objective of the project was to put in place a framework for environmental management and build capacity for environmental and radiological site characterisation, leading to baseline generation of potential uranium mining sites in Mauritania and building capacity for monitoring of radionuclides in the environment.

In addition, the United States Geological Survey, in co-operation with the Ministry of Petroleum, Energy, and Mines of the Islamic Republic of Mauritania, conducted a preliminary mineral resource assessment for 12 commodities (including uranium), and in 2015 published the assessment as Open-File Report 2013–1280, "Second projet de renforcement institutionnel du secteur minier de la République Islamique de Mauritanie (PRISM-II) phase V". With respect to uranium resources, the assessment report indicated that Mauritania has 80 known uranium mineral occurrences and, at the time, was a focus of active exploration for uranium by a number of private companies. Seventeen occurrences have had resource estimates published and can be considered as mineral deposits. Fourteen of these are calcrete-type deposits with total resources of 138.3 million tonnes at an average grade of 331 ppm U_3O_8. The three bedrock-hosted deposits are granite-hosted vein/shear zone type deposits with total resources of 46.5 million tonnes at a grade of 248 ppm U_3O_8 (0.02% U). Further, permissive tracts for undiscovered uranium deposit types were also delineated.

In Namibia, over 60 exploration licences had been issued until early 2007, when a moratorium on new licences was imposed by the Namibian government pending development of new policies and legislation, primarily in response to concerns about water and energy requirements of uranium mining. In January 2017, the Namibian government lifted the 10-year moratorium on new applications for exploration licences for nuclear fuel minerals and as of the end of 2019, 52 new licences had been granted.

Box 1.4. ***U-pgrade™*** **ore beneficiation process**

Namibian calcrete ores are conglomerates of predominantly quartz, feldspars, biotite and carbonate cemented together by a clay matrix. The uranium mineral carnotite occurs predominantly as liberated particles within the clay matrix, sometimes in fractures or on the surface of larger particles. The presence of significant quantities of carbonate minerals excludes acid leaching as a process route.

The calcrete deposits are generally <20 m deep with the top 3 to 4 m, representing about 15% of the deposit, containing high sulphate (gypsum) levels. The sulphate consumes the alkali leach reagent, thus 15% of the deposit cannot be leached economically with acid or alkali.

U-pgrade™ is a beneficiation process that uses commonly known and well understood unit operations configured in an unconventional manner for uranium. The process was developed in-house by Elevate Uranium Ltd and has granted patents in various countries.

U-pgrade™ exploits the properties of the gangue minerals to reject them through the process, producing a concentrate of <5% of the mined mass. For example, at Elevate Uranium Ltd's Marenica Uranium Project in Namibia, the process increases ore grade from 93 to 5 000 ppm U_3O_8. Due to the rejection of acid consuming carbonate minerals, the low mass, high grade concentrate can be acid leached at a lower temperature and lower cost than the high temperature alkali leach.

U-pgrade™ provides a way to process the high sulphate calcrete ore that otherwise cannot be treated by conventional processes. This effectively increases the resource by 15%.

The ***U-pgrade™*** process reduces the capital and operating costs by ~50% compared to conventional processes. The production of a low mass high grade concentrate provides processing options for the concentrate, which can either be leached and refined on site or transported off site to be leached and refined by a third party. The latter option reduces the capital expenditure on site without the need for a leach and refinery. As such, ***U-pgrade™*** provides a practical means by which lower grade or small deposits can be developed.

Among the environmental benefits of ***U-pgrade™***:

- The reduced mass to be leached reduces the volume of acid transported to the mining operation.
- The carbonate concentrate produced during the process can be added to the leach tail to neutralise the acid and precipitate any metals, producing inert tailings.

The tailings dam is <5% of the size of conventional processing

Exploration activities between 2018 and 2021 focused on developing properties and little work was undertaken at the existing mine sites. Bannerman Resources continued work on its Etango Project, where two-thirds of the identified resources (82 400 tU in situ) are located within 200 m of the surface. Reptile Mineral Resources continued exploration of its Omahola Project, including the Ongolo and MS7 alaskite as well as the Inca skarn deposits, and the Tumas, Tubas and Aussinanis surficial calcrete deposits, with total identified in situ resources amounting to 75 353 tU. Between 2019 and 2021, the focus was to advance the Tumas Project by conducting a scoping study that directly led into a pre-feasibility study completed in February 2021 that confirmed the technical and economic viability of the project. A definitive feasibility study followed that is expected to be completed in 2022. Elevate Uranium Ltd (formerly Marenica Energy) resumed work on the Marencia Project after suspending drilling activities in 2016 due to depressed market conditions. In 2020, Elevate announced a new uranium discovery at EPL 7278 ("Hirabeb"), then conducted an airborne EM survey of the Hirabeb tenement and the associated paleochannel system in April 2021. In south-eastern Namibia, Russian owned Uranium One, through its Namibian daughter company Headspring Investments Pty., discovered and has been developing a new sandstone-type uranium deposit (Wings) that is potentially amenable for extraction by ISL. Wings contains JORC compliant in situ resources amounting to 14 700 tU RAR, 9 900 tU IR, with an exploration potential of 40 000 tU.

Uranium exploration and mine development expenditures in Namibia amounted to USD 3.3 million and USD 3.7 million in 2017 and 2018, respectively, before increasing to USD 6 million in 2019, USD 11.1 million in 2020 and USD 19.2 million in 2021. A total of 218 223 m (3 939 holes) were drilled in Namibia from 2018 to 2021, with 79% of the drilling for uranium exploration.

Uranium exploration and development expenditures were not reported for all operations in Niger in this edition. Reported expenditures for GoviEx in 2018 and 2019 and Global Atomic Corporation (GAC) in 2020 amounted to USD 6.9 million in 2018, USD 2.9 million in 2019 and USD 2.5 million in 2020 (expenditures in 2021 were not reported). In 2017-2018 GAC commenced a new drilling programme targeting various areas of the Dasa project and a total of 59 holes amounting to 26 479 m were completed, leading to resource estimates of 39 080 tU indicated and 33 695 tU inferred. In 2020, GAC completed a preliminary economic assessment, then submitted an environmental impact statement and applied for a mining permit. In December 2020, a Presidential Decree granting the mining permit was approved by the Council of Ministers. GAC also received three-year permit extensions for each of its six exploration properties in Niger.

GoviEx developed a NI 43-101 integrated development plan for five deposits (Marianne, Marilyn, Miriam, MSNE and Maryvonne) comprising the Madaouela project, with total in situ uranium resources amounting to 42 603 tU measured and indicated and 10 647 tU inferred. In September 2019, the Republic of Niger approved the revision to the Madaouela mining permit to include 1 550 tU in the measured and indicated categories associated with the Miriam deposit as well as 6 880 tU in the measured and indicated categories associated with Madaouela South North East ("MSNE") deposit. Both were previously situated within the Agaliouk exploration permit. In 2020, GoviEx completed an updated feasibility study and announced the results in February 2021. Open-pit mining is planned with standard truck and shovel operations for the Miriam deposit at a planned rate of 1 Mt per year of ore feed to the process plant, with the Marianne-Marilyn and MNSE-Maryvonne deposits to be mined by room and pillar. The project's life is forecast to last 20 years, producing an estimated total of 19 100 tU, averaging 950 tU per annum.

In 2019-2020, Orano continued exploration and development activities within the Cominak and Somaïr mines perimeters and in the Arlit concession. Somaïr drilled 16 240 m in 2017, 8 150 m in 2018, and was planning 11 863 m in 2019. In October 2018, Somaïr was granted the Artois deposit concession. The government of Niger renewed Pan African Minerals exploration licences (Ouricha 1 and 2, Tegmert 1 and 2) in 2018, but no activity was reported in 2019 and 2020.

In Senegal, although there has been no exploration and mining development for uranium since 2016, undiscovered conventional resources of 1 500 tU have been reported in the Red Book. However, considering the amount of drilling and analyses completed in the Saraya area and the resource estimation completed by COGEMA, the previously reported undiscovered resources have been reclassified as inferred resources.

For South Africa, no exploration and mine development expenditures were reported in this edition. Low uranium market prices have not only slowed exploration activity but have shelved projects, including Harmony Uranium TPM (Tshepong, Phakisa and Masimong) and the Free State Tailings Uranium Project, which had both been advanced to the feasibility stage, as well as the Henkries Project in the Namaqualand, Northern Cape Province, and the Ryst Kuil and Quaggasfontein areas (Karoo projects). In 2018, Mintails Mining South Africa (Pty) Ltd and several related companies announced their liquidation. Mintails used to mine and process gold and uranium from waste piles and open pits in Krugersdorp near Johannesburg.

For Tanzania, exploration and development expenditures were not reported in this edition. The main focus of activity had been directed at the Nyota deposit (Mkuju River Project), where ISL tests were conducted over 10 months in 2016 using a two-well pattern and a final report was issued in 2017. The results confirmed the amenability of the portion of the resources situated below the water table for extraction by ISL. During 2017, rehabilitation of aquifers and the ground surface was completed following the ISL tests. In December 2016, Mantra Resources (purchased by ARMZ of Russia in 2011) applied to the Ministry of Energy and Minerals of Tanzania for suspension of its special mining licence due to unfavourable uranium market conditions. In September 2017, the ministry approved the request. In 2020, Mantra Resources shifted its focus from ISL to open-pit mining and decided to move ahead with a pilot processing plant during 2021-2022 to proceed with a small-scale pilot open-pit mining operation during 2023-2025. An annual pilot plant capacity of 15 000 tonnes of ore assumes production of 5 tU/yr. In 2021, Mantra/Uranium One applied to the Tanzanian government for permits for uranium exploration as well as the siting and construction of a uranium mine processing facility.

Uganda does not report data to the Red Book but may in future since the IAEA has continued to support Uganda’s efforts to identify and evaluate uranium resources through the Technical Co-operation programmes “Strengthening the National Capacity for Uranium Exploration and Evaluation” from 2014 to 2017, and “Enhancing Regional Capabilities for a Sustainable Uranium Mining Industry” from 2018 to 2021. The government continues to evaluate national uranium resources utilising their Geological Survey and Mines Department as part of long-term planning as the country considers adding nuclear energy to its future energy mix.

In Zambia, after acquiring the Mutanga and Chirundu projects in 2016 and 2017, respectively, GoviEx Uranium Inc. (GoviEx) released a new preliminary economic assessment for the Mutanga uranium project, including mineral resource estimates for Mutanga, Dibwe, Dibwe East, Gwabe, Njame and Njame South sandstone-hosted ore deposits in 2017. The project currently consists of five main uranium deposits under three fully permitted contiguous mining licences, totalling 140 km in strike length. It also includes two more prospective licences covering 100 km². Due to the COVID-19 pandemic, GoviEx employees worked remotely in 2020. In 2021, GoviEx planned soil sampling and geological mapping in the Mutanga area, as well as an 8 000 m down-hole percussion drilling programme (100 m x 50 m grid), focused on the Dibwe East deposit and new areas defined by previous trench sampling east of Dibwe East. Although total exploration and mine development expenditures were not reported for this edition, exploration expenditures by GoviEx amounted to USD 710 000 in 2017, USD 607 000 in 2018, USD 502 000 in 2019 and USD 536 000 in 2020.

Middle East, Central and Southern Asia

Uranium exploration and mine development expenditures in the Middle East, Central and Southern Asia region amounted to about 20% to 30% of total reported global expenditures, mainly in India, Kazakhstan and Jordan, supplemented for the first time by reported uranium exploration activities in Bangladesh and the Kingdom of Saudi Arabia.

Bangladesh provided information for this edition of the Red Book, for the first time since 1988, as it launches its civil nuclear power programme. During 2018-2020, the Bangladesh Atomic Energy Commission (BAEC), through the Institute of Nuclear Minerals, Atomic Energy Research Establishment, completed a preliminary programme of uranium and thorium exploration over a 12 km^2 area in the Jaintiapur and adjacent Sylhet areas of north-east Bangladesh, spending a total of USD 21 000 from 2019 to 2021.

In **India**, government exploration and development expenditures remained relatively steady at above USD 60 million from 2017 to 2019, up from USD 40 million to USD 50 million since 2012. They then declined to USD 48 million in 2020, but were expected to rise to over USD 65 million in 2021. In 2020, India ranked second to Canada in uranium exploration and mine development expenditures.

As in recent years, exploration activities remain concentrated on various Precambrian and Palaeozoic through Cenozoic basins, shear zones, fold belts and metamorphic complexes. Extensive exploration, including ground and heliborne geophysical, ground geological, radiometric and geochemical surveys, and drilling are planned in other geological domains of the country that have the potential to host uranium. These efforts have resulted in a 13% increase in RAR and a 7% increase in speculative resources from 2019 to 2021, due to appreciable resource additions in the contiguous area of the stratabound deposits in the southern part of the Cuddapah Basin and the extension areas of known deposits in the Singhbhum Shear Zone, Bhima Basin and North Delhi Fold Belt.

Iran did not respond to the Red Book 2022 questionnaire, so nothing is available beyond reported government exploration and development figures, with expenditures of USD 17.3 million in 2016, USD 39.2 million in 2017, USD 13.6 million in 2018 and USD 9.3 million (expected) in 2019. Exploration accounted for 53% of total expenditures over this same period. Exploration drilling and trenching totalled 19 918 m (114 holes) and 8 043 m (244 trenches), respectively, whereas development drilling totalled 17 608 m (3 319 holes).

Exploration activities in Iran have followed a general plan in favourable areas from reconnaissance to more detailed phases. Reconnaissance and prospecting phases are being undertaken over much of the country and uranium mineralisation with positive indications has been found in a variety of geological environments. Targets include granite-related, metasomatic, volcanogenic, intrusive and sedimentary types of deposits.

In Jordan, government exploration expenditures decreased from USD 4.8 million in 2018 to USD 3.5 million in 2019 and USD 2.4 million in 2020 but were expected to increase slightly to 2.8 million in 2021. Over that same period, the Jordan Uranium Mining Company (JUMCO) completed 6 944 m of trenching (1 736 trenches), all in 2018. Plans for 2019-2020 included a drilling programme on a 50 x 50 m grid in selected areas to upgrade resources in preparation for pre-feasibility studies. During the second half of 2019, JUMCO completed the development of the wireline logging capacity required to execute the planned drilling campaign, but during the first quarter of 2020 COVID-19 pandemic work restrictions stopped all exploration activities, and the plan was put on hold.

Uranium production cycle activities in Jordan have been supported by several IAEA Technical Co-operation projects over the last few years, most recently the “Enhancing Capabilities in Extracting Uranium from Local Ores on a Pilot Scale Level” project in 2018 and 2019; “Supporting Capacity Building in Member States for Uranium Production and Safety of Naturally Occurring Radioactive Material Residue Management” and “Developing a Detailed Engineering and Complete Feasibility Study for Uranium Extraction from Local Ores” projects started in 2020; and the “Enhancing the National Capabilities in Exploiting Uranium Ores in a Safe and Environment Friendly Manner” project started in 2022.

In Kazakhstan, exploration and development expenditures decreased from USD 37.3 million in 2018 to USD 18.8 million in 2019 and USD 13.4 million in 2020 and were expected to decline to USD 9.9 million in 2021. These expenditures are the lowest since Kazakhstan started ramping up its exploration and development activities in 2007 and 2008. During the most recent reporting period (2018-2021), 12% of the total expenditures were devoted to mine development activities, the remainder to exploration. Drilling over this same period amounted to 3 025 707 m (6 208 holes), with development drilling accounting for 1 312 844 m (2 889 holes).

During 2019 and 2020, exploration was undertaken at Inkai, Budenovskoye in the Shu-Sarysu Uranium Province and at the Northern Kharasan and Zarechnoye deposits in the Syrdaria Uranium Province. This resulted in an increase of in situ IR resources of 55 409 tU at sites No. 6 and No. 7 of the Budennovskoye field. Total identified resources decreased by 111 725 tU, however, due to mining depletion and transfer of the Kosachinoye field resources (OP and UG; 121 630 tU) to the sub-economic category. Kazatomprom also contracted JSC “Volkovgeology” in 2020 to complete a state geological study focused on the potential for discovery of new “sandstone” type deposits suitable for ISL in perspective areas of the Shu-Sarysu uranium province.

Re-evaluations of prognosticated and speculative resources were also undertaken in 2019 and 2020, resulting in the addition of 4 900 tU in high-cost prognosticated resources and over 33 000 tU in speculative resources. Of the 114 696 tU prognosticated resource total, 113 166 tU are related to sandstone-type deposits and 1 530 tU to the metasomatite type. Of the 219 380 tU total speculative resources, 85% relate to the sandstone-type and 15% relate to the unconformity or metasomatite type mineralisation.

The Kingdom of Saudi Arabia provided information for this edition of the Red Book, the first time that it has done so. The mining and metals processing sector has grown significantly over the last few years and, in line with Saudi Arabia’s Vision 2030 goal to have a mining sector that contributes to the national economy, a strategic exploration programme for mineral resources, including uranium, was initiated. From March 2017 to March 2019, the first phase of uranium and thorium exploration was conducted, including the evaluation of nine designated areas (including 36 subareas) covering a total area of 27 000 km^2 across Saudi Arabia. Exploration targets included intrusive, volcanic, phosphate, calcrete and sandstone-hosted deposit types. The Ghurayyah, Jabal Sayid and Thaniyat Turayf subareas were selected for detailed exploration and the estimation of inferred resources. The cost of the exploration programme was USD 37 million between 2017 and 2020, with USD 849 000 in expected expenses in 2021.

Although no conventional resources were reported from these efforts, inferred unconventional resources were reported, including uranium resources associated with Nb, Zr, REE, Ta + Th, in peralkaline granite and pegmatite in the Ghurayyah and Jabal Sayid areas, and uranium associated with phosphate horizons. Total in situ unconventional uranium resources totalled 77 731 tU, including 63 171 tU associated with the intrusive plutonic deposit type and 14 560 tU associated with the phosphorite type.

The Saudi Nuclear Regulatory and Radiation Commission (NRRC), a legal public organisation with financial and administrative autonomy, aims to regulate activities, practices, and facilities involving the peaceful use of nuclear energy and ionising radiation as Saudi Arabia prepares to bring nuclear power into its energy mix by the mid-2030s, introducing demand for uranium to fuel the reactors.

Uranium production cycle activities in Saudi Arabia have been supported by IAEA Technical Co-operation activities, most recently in 2019 with an Integrated Nuclear Infrastructure Review Mission and workshops on “Developing a Policy and Strategy on Nuclear Fuel Cycle” and “Uranium Production Feasibility Studies: Processing, Economic, Social and Environmental Aspects”, all of which focused on the front-end and back-end of the nuclear fuel cycle, as well as project management.

Uzbekistan reported both resources and production for this edition of the Red Book, but only related to that of the Navoi Mining and Metallurgy Combinat (NMMC). In December 2019, it was reported that France and Uzbekistan had established the French-Uzbek uranium joint venture, the Nurlikum Mining LLC, which is 51% owned by Orano and 49% by Uzbekistan’s State Committee on Geological and Mineral Resources (GoscomGeology). Nurlikum Mining will conduct uranium exploration and mining operations throughout Uzbekistan, focusing on sandstone-type uranium mineralisation in the Djengeldi region of Kyzylkum province. Orano will contribute capital and technology to the JV, while the Uzbekistan side will contribute historical exploration results. Nurlikum’s first field exploration commenced in 2020 and consisted of 40 drill holes. The planned exploration campaign for 2021 envisioned the drilling of around 300 boreholes.

South-eastern Asia

Uranium exploration and mine development activities in the South-eastern Asia region amounted to <1% of total reported global expenditures throughout the period 2018 to 2021. Ongoing exploration in Indonesia and Viet Nam, along with investigations into uranium processing in Viet Nam, were reported for this edition of the Red Book, although associated expenditures in Viet Nam have not been reported since 2017.

In Indonesia, exploration expenditures declined from USD 121 000 in 2017 to USD 81 000 in 2018, then increased to USD 246 000 in 2019 before dropping to USD 42 000 in 2020 and USD 25 000 in 2021. A drilling programme of 425 m (6 holes) to test for mineralisation in alkaline lava flows was executed for 2019, as well as detailed geological mapping of lateritic soil in eastern Takandeang, re-evaluation of previously discovered anomalous radiometric values in Harau and reconnaissance geological, geochemical, and radiometric mapping, and radon measurements, in Melawi. In 2020, exploration was conducted in the Mamujui (radon surveys and geochemistry of drill core), Bangka Island (detailed radiometric and radon surveys, and spectral logging measurements in 13 holes [20-70 m depth] that tested a placer deposit), and Melawi regions (preliminary grid-based radon surveys).

In Viet Nam, uranium mineralisation is associated with rare earth element deposits (Lao Cai province), phosphate deposits (Cao Bang province), and sandstone and coal deposits (Quang Nam province). Government uranium exploration expenditures amounted to USD 1.8 million and 1.5 million in 2016 and 2017, respectively, but no expenditures have been reported since.

Activities to estimate uranium potential of 12 orebodies in the Palua-Parong area were undertaken from 2016 to 2019. In support of these efforts, research on ore leaching treatment methods, laboratory and pilot-scale tests, as well as investigations on the management of mining wastes and tailings, have been carried out by the Institute for Technology of Radioactive and Rare Elements (ITRRE). The results show that the heap leach method is suitable for the low-grade Parong ore, with uranium recovery greater than 75% achieved.

Current ITRRE activities are focused on the recovery of thorium and uranium from rare earth concentrates, and a continuous counter-current extraction process for the simultaneous recovery of thorium and uranium from the Yen Phu rare earth concentrate leach solutions was developed. Separation of thorium and uranium from xenotime leach solutions was achieved by solvent extraction using primary and tertiary amines. Results show that the extraction method is suitable for the recovery of thorium and uranium from rare earth concentrate with thorium and uranium purities of greater than 99%. Uranium exploration and research on uranium extraction from uranium ores are continuing but no production centre has been planned to date.

East Asia

Uranium exploration and mine development expenditures in the East Asia region amounted to 25% and 30% of total global expenditures in 2018 and 2019 respectively, before dropping to <1% of global expenditures in 2020 and 2021, since expenditures in China for these years were not reported and only expenditures in Mongolia were made available for this edition of the Red Book.

China did not respond to the questionnaire for this edition of the Red Book. Total non-domestic development expenditures by China had decreased from USD 378 million in 2016 to USD 108.1 million in 2017, USD 41.5 million in 2018 and USD 23.6 million in 2019, as the acquisition and subsequent ramp up in development of the Husab mine in Namibia was completed. Husab was acquired in 2012 by Uranium Resources Co., Ltd, a subsidiary of state-owned China General Nuclear Power Group (CGN).

In addition to development of the Husab mine, overseas expenditures have been reported for several other uranium projects mainly in Kazakhstan, Namibia and Niger. In 2006, the state-owned China National Nuclear Corporation (CNNC) signed an agreement to develop the Azelik-Abokurum deposit in Niger, but after about 670 tU were produced the mine was idled in 2014 and it is unlikely to be restarted. CNNC purchased a 25% equity stake of the Langer Heinrich uranium mine from Paladin Energy, acquiring a total of 934 tU under the shareholders' equity in 2017, prior to the mine being idled. On 26 November 2018, CNNC signed a share-sale agreement with Rio

Tinto to buy a 68.62% equity stake of the Rössing uranium mine in Namibia. CGN is also in a partnership with Kazatomprom for the Semizbay and Irkol ISL mines in Kazakhstan and in May 2014 agreed to buy uranium from Uzbekistan through to 2021 for USD 800 million.

Domestic uranium exploration and mine development expenditures in China were relatively stable from 2016 to 2018 but were expected to increase to USD 154 million in 2019. Over 90% of these expenditures were exploration related. In response to the challenges brought about by sustained low uranium prices and efforts to meet ecological goals announced by the central government, Chinese uranium companies reorganised in 2017 and 2018 and a domestic industry focused on production dominated by ISL in northern China, supplemented by underground mining in southern China was developed, and the main exploration effort was shifted to ISL.

Industrial ISL tests, carried out in some parts of the Erdos and Erlian sandstone-type uranium deposits in Inner Mongolia, produced encouraging results that may result in these deposits becoming the principal uranium production centres in China.

Over the past several years, the IAEA has supported China through the Technical Co-operation programme. Some of the most recent projects include the project "Developing Exploration Techniques for Deep Blind Deposits in Typical Hydrothermal Uranium Ore Fields", which was conducted from 2014 to 2016; "Studying Identification Technology and Technical Economic Evaluation of Typical Sandstone-hosted Concealed Uranium Deposits", which began in 2018; "Implementing Exploration Techniques for Paleochannel Sandstone-Hosted Uranium Deposits and Fluid-Rock Interaction in In-Situ Leaching Processes", which carried out from 2020 to 2021; and the current project, "Evaluating the Technical and Economic Viability of Uranium Resources in Different Exploration Stages", which started in 2022.

Japan reported an increase in non-domestic government exploration development expenditures from USD 2.2 million in 2017 and 2018 to 3.2 million in 2019, with a subsequent decline to 3.1 million in 2020 and USD 2.6 million expected in 2021. The Japan-Canada Uranium Co. Ltd (JCU), which took over JNC's Canadian mining interests, is continuing exploration activities in Canada while JOGMEC continues exploration activities in Uzbekistan and Namibia. Japanese private companies hold shares in companies developing uranium mines and in those operating mines in Australia, Canada, Kazakhstan and Niger. In December 2019, Uzbekistan agreed to sell uranium to two Japanese trading companies. Uzbekistan signed separate contracts with ITOCHU (valued at USD 636.4 million) and Marubeni (valued at USD 510.1 million) with both agreements covering uranium deliveries between 2023 and 2030.

In Mongolia, reported domestic exploration and development expenditures by industry declined from USD 4.9 million in 2018 to USD 158 000 in 2019, then to USD 71 000 in 2020 before picking up to USD 74 000 in 2021. No development expenditures were reported. Exploration drilling in 2019 totalled 1 100 m with none reported in 2020 and 2021, a sharp decline from peak drilling of 23 655 m in 2017. Four companies are engaged in exploration activities in Mongolia focusing on the identification of sandstone-type uranium mineralisation amenable to ISL mining.

Major exploration activities during 2019-2020 were conducted by Badrakh Energy on the ISL amenable Zuuvch Ovoo and Dulaan uul uranium deposits in southeast Mongolia. As a result, uranium resources of the Zuuvch ovoo deposit were increased to 93 291 tU in situ and a technical report was submitted to the Mongolian Professional Committee of Resources in February 2020. After receipt of all required authorisations from government authorities including validation of an environmental impact assessment and environmental management plan, a pilot ISL test was started in 2021. On 10 August 2021, the first kg of uranium concentrate was produced. Operations were planned to continue in 2022 to provide information confirming key technical and economical parameters for future industrial production.

An IAEA Technical Co-operation project, Regional Asia Pacific, was initiated in 2016 and continued through 2019. The project, "Conducting the Comprehensive Management and Recovery of Radioactive and Associated Mineral Resources", is aimed at supporting member states in the Asia-Pacific region in developing sustainable mining of deposits with associated radioactive minerals. Uranium production is one potential aspect of economic development in the region where balancing consumption and production is of interest. Though the region (especially China) is expected to grow significantly in terms of nuclear power production, a large part of the current and future uranium requirements is expected to be met by imports. Though potential for increasing domestic uranium production exists, several factors preventing this from materialising will be addressed to strengthen capacities through the establishment of centres of excellence in member states. Other IAEA support includes a Technical Co-operation project, "Developing Human Resources in Nuclear Science and Establishing Electron Beam Capacities for Flue Gas", which started in 2018, and most recently in 2022, an Integrated Uranium Production Cycle Review Mission for the Mongolian Nuclear Energy Commission.

Pacific

Uranium exploration and mine development expenditures in the Pacific region (i.e. Australia) accounted for about 2% of total global expenditures reported for this edition of the Red Book from 2018 through 2021. Mine development activities slowed, however, after government approvals were obtained, as developers await improved market conditions before bringing these projects into production.

In Australia, domestic exploration expenditures by industry continued to decline from USD 15.1 million in 2017 to USD 9.0 million in 2018, USD 7.1 million in 2019 and USD 4.6 million in 2020, with a rise to USD 6.9 million expected in 2021. During this period, uranium exploration was most active around known resources in Western Australia and South Australia, as low uranium market prices limited greenfield activity.

In Western Australia, Vimy Resources was granted government approvals for the Mulga Rock project in March 2017, released a definitive feasibility study in 2018, and in September 2021 the Western Australian Department of Mines, Industry Regulation and Safety approved the Mulga Rock Mining Proposal and associated Mine Closure Plan. The project involves shallow open-pit mining of 4 polymetallic deposits, with 1 346 tU produced annually over 15 years. The Yeelirrie project, one of the world's largest surficial uranium deposits, received environmental approval from the Western Australia government in January 2017 and the Commonwealth government in April 2019. Wholly owned by Cameco Australia Pty Ltd, production of nearly 3 300 tU per annum over 19 years utilising open-pit mining and alkaline leach technology is planned. The unconformity-related Kintyre uranium deposit, also wholly owned by Cameco Australia Pty Ltd, is planned to produce 2 290 tU per annum over 15 years. Suited for open-pit mining with the uppermost parts of the resource 50 m below surface, Kintyre secured environmental approval for the Kintyre project in 2015 from both the Commonwealth and Western Australian governments. Toro Energy Ltd, the owner of the Wiluna project, a surficial calcrete-hosted regional resource comprised of six deposits, received environmental approvals from the Western Australian government and the Commonwealth in 2017. A shallow strip excavation to a maximum depth of 15 m is planned, with alkaline agitated leaching in tanks at elevated temperatures to process the ore. Production is estimated to be approximately 577 tU per annum. All four of the projects, poised to enter production, are on hold until uranium market conditions improve.

In South Australia, the sandstone-type Honeymoon deposit, operated by Boss Energy Ltd, is approved for mining and exploration, and metallurgical test work continued with total identified, recoverable resources of 23 306 tU. In June 2021, Boss Energy released an Enhanced Feasibility Study and in June 2022 the company announced a final investment decision to develop the Honeymoon project with a first uranium production scheduled for Q4 2023 ramping up to about 940 tU within 3 years.

Through 2019 and 2020, Australian-listed mineral companies were involved in exploration activities for uranium in countries such as Namibia and Tanzania. However, non-domestic expenditures were not reported for this edition and the past several editions.

Uranium production

In 2020, 17 countries produced uranium, with the global total amounting to 47 342 tU. Kazakhstan's continuous growth in production came to an end in 2017 as production cuts were instituted to reduce supply to an oversupplied market. Nonetheless, Kazakhstan remained by far the world's largest producer, even as production was eased back from 21 705 tU in 2018 to 19 447 tU in 2020. Kazakhstan's production alone in 2020 amounted to more than the combined production in that year from Australia, Namibia, Canada and Uzbekistan, respectively the second, third, fourth and fifth largest producers of uranium that year. Germany and Hungary were the only countries that reported their entire 2020 uranium production from mine remediation activities (a combined total of 10 tU). In the recent past, both Germany and France had been reporting a few tU of production through remediation activities, but they are unlikely to produce uranium by this means in the coming years as remediation has resulted in reduced amounts of uranium in water captured and treated during the remediation process. In Germany, future water treatment at the Königstein mine site will still be required but without any special separation of uranium. Table 1.17 summarises major changes in uranium production and Table 1.18 shows production in all producing countries from 2018 to 2021. Figure 1.5 shows 2020 production shares, and Figure 1.6 illustrates the evolution of production shares from 2012 to 2021.

Table 1.17. **Production in selected countries and reasons for major changes**

(as of 1 January 2021, tonnes U)

Country	Production 2018	Production 2020	Difference	Reason for changes in production
Australia	6 526	6 195	-331	Decline in production from Olympic Dam and declining production from stockpiled ore at Ranger as production stopped 8 January 2021.
Canada	6 996	3 878	-3 118	Production idled at Rabbit Lake, McArthur River and Key Lake due to depressed uranium market prices and reduced activity due to COVID-19 pandemic work restrictions.
Kazakhstan	21 705	19 477	-2 228	Overall decline as Kazatomprom flexes down production to the target of 20% until 2022.
Namibia	5 520	5 412	-108	Husab continues production ramp up but higher calcium content in Rössing ore limiting processing plant throughput.
Niger	2 878	2 991	113	Reduced production at Somaïr open pit balanced by Cominak production increases ahead of Cominak shutdown on 31 March 2021 due to ore depletion and high operating costs.
South Africa	346*	62*	-284	Operations at the uranium plant of AngloGold's Mine Waste Solutions ceased in 2018, other operations limited by low market prices and COVID-19 work restrictions.
United States	277	8*	-269	Decline due to mine production being idled or reduced at a number of facilities due to an extended period of low market prices.

* Secretariat estimate.

Table 1.18. **Historical uranium production**

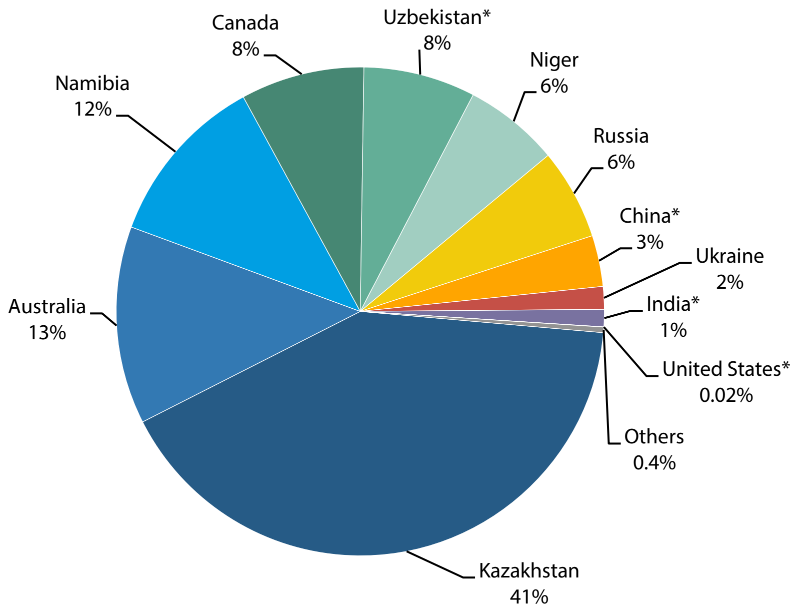
(as of 1 January 2021, tonnes U)

Country	Pre-2018	2018	2019	2020	Total to 2020	2021
Argentina	2 582	0	0	0	2 582	0
Australia	212 502	6 526	6 613	6 195	231 836	3 817
Belgium	686	0	0	0	686	0
Brazil	4 216	0	0	0	4 216	30
Bulgaria	16 347	0	0	0	16 347	0
Canada[a]	524 929	6 996	6 944	3 878	542 747	4 692*
China	44 679	1 620	1 600*	1 600*	49 499	1 600*
Congo, Dem. Rep. of	25 600	0	0	0	25 600	0
Czech Republic[b]	112 119	34	42	34	112 229	36
Finland	30	0	0	0	30	0
France	80 978	0	0	0	80 978	0
Gabon	25 403	0	0	0	25 403	0
Germany[c]	219 765	0	24[d]	7[d]	219 796	0
Hungary	21 078	5[d]	3[d]	3[d]	21 089	3[d]
India*	12 568	385*	460*	540*	13 953	600*
Iran, Islamic Rep of[e]	98	20	21*	21*	160	21*
Japan	84	0	0	0	84	0
Kazakhstan	316 593	21 705	22 808	19 477	380 583	21 819
Madagascar*	785	0	0	0	785	0
Malawi	4 217	0	0	0	4 217	0
Mexico	49	0	0	0	49	0
Mongolia	535	0	0	0	535	0
Namibia	131 224	5 520	5 477	5 412	147 633	5 753
Niger	143 261	2 878	2 982	2 991	152 112	2 250
Pakistan*	1 574	45*	45*	45*	1 709	45*
Poland	650	0	0	0	650	0
Portugal	3 720	0	0	0	3 720	0
Romania	18 974	0	0	0	18 974	0
Russia	167 821	2 904	2 911	2 846	176 482	2 635
Slovak Republic	211	0	0	0	211	0
Slovenia[f]	387	0	0	0	387	0
South Africa	160 701	346*	185*	62*	161 294	192*
Spain[g]	5 028	0	0	0	5 028	0
Sweden[g]	200	0	0	0	200	0
Ukraine	132 143	790	796	711	134 440	455
United States	376 646	277	67	8*	376 998	4*
USSR[h]	102 886	0	0	0	102 886	0
Uzbekistan	137 016	3 450*	3 500*	3 512*	147 478	3 520*
Zambia	86	0	0	0	86	0
Total	3 008 371	53 501	54 478	47 342	3 163 692	47 472
Total OECD-only	1 559 062	13 838	13 693	10 125	1 596 718	8 552

* NEA/IAEA estimate. (a) Includes production from refinery wastes (14 tU in 2015, 17 tU in 2016 and 21 tU in 2017) and 61 tU recovered from cleaning Key Lake mill circuits in 2018. (b) Includes 102 241 tU produced in the former Czechoslovakia and CSFR from 1946 through the end of 1992. (c) Production includes 213 380 tU produced in the former GDR from 1946 through the end of 1989. (d) Production from mine rehabilitation efforts only. (e) Updated pre-2018 production figures provided by Iranian authorities 8 March 2021. (f) Pre-2018 total updated after review of historic records. (g) For pre-2010, other sources cite 6 156 tU for Spain, 91 tU for Sweden. (h) Includes production in former Soviet Socialist Republics of Estonia, Kyrgyzstan, Tajikistan, Uzbekistan.

Figure 1.5. **World uranium production 2020**

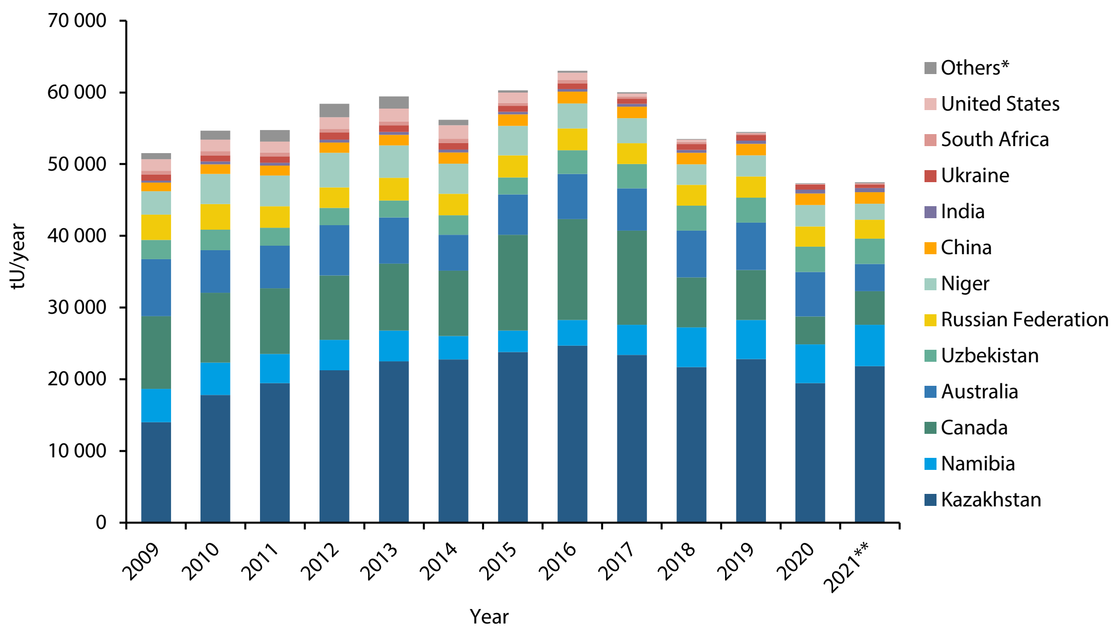
(47 342 tU, as of 1 January 2021)



* NEA/IAEA estimate.

Figure 1.6. **Recent world uranium production**

(tU/year)



* "Others" includes the remaining producers (see Table 1.18 and previous Red Book editions).

** NEA/IAEA estimate.

Namibia moved up to 3rd place as Husab ramped up production and Niger moved up to 6th place as 2020 production of 2 991 tU edged out Russia's production of 2 846 tU. Canada's production declined sharply, dropping it to the 4th place (3 878 tU), as some key facilities were idled because of poor market conditions and COVID-19 pandemic work restrictions limited activities at others. Australia moved up to 2nd place as production declined much less so than in Canada. Uzbekistan continued to rank as the 5th largest producer in 2020 with production of 3 512 tU. The top five producing countries (Kazakhstan, Australia, Namibia, Canada and Uzbekistan) dominated uranium production, accounting for 82% of world production in 2020. Ten countries: Kazakhstan (41.1%), Australia (13.1%), Namibia (11.4%), Canada (8.2%), Uzbekistan (7.4%), Niger (6.3%), Russia (6.0%), China (3.4%), Ukraine (1.5%) and India (1.1%) accounted for over 99% of world production in 2020 (Figure 1.5).

Overall, world uranium production increased slightly (1.8%) from 53 501 tU in 2018 to 54 478 tU in 2019, then declined by 13% to 47 342 tU in 2020 as producers instituted production cuts to reduce supply in a saturated market. These planned reductions were greatest in Canada and Kazakhstan. Production also declined dramatically in the United States as mine production was suspended at several facilities due to an unfavourable market (Table 1.18). Within OECD countries, production decreased from 21 521 tU in 2016 to 13 838 tU in 2018 and 13 693 in 2019, primarily due to planned production cuts in Canada and declining production in the United States. It then dropped (26%) to 10 120 tU in 2020 and further to 8 477 tU in 2021 as operations at the Ranger mine in Australia wound down before closing in early 2021.

World production was expected to increase marginally (0.3%) to 47 472 tU in 2021, mainly due to continued production cuts in Canada and Kazakhstan, as well as declining production in Australia following closure of Ranger mine and in Niger following closure of Cominak. In Canada, mining at Rabbit Lake was suspended in mid-2016, then mining at the McArthur River and milling at Key Lake was suspended at the end of January 2018, all due to low uranium prices. In 2017, Kazatomprom announced that it planned to reduce production by a total of 20% through 2021 to better align production by the world's largest producer with demand. On 19 August 2020, Kazatomprom announced that it intended to extend its plan to flex down production by 20% through 2022 (WNA, 2020a).

In addition to planned production cuts, the COVID-19 global pandemic has also affected operations in several uranium producing countries. In Canada, on 23 March 2020, Cameco announced that it had suspended production at the Cigar Lake mine and Orano announced that it had suspended work at the McClean Lake mill in response to the pandemic. In Kazakhstan, on 7 April 2020, JSC National Atomic Company Kazatomprom announced that it was reducing operational activities at all uranium mines for a period of three months due to the pandemic. In Namibia, activity at the Rössing mine was temporarily reduced to a minimum, and in Australia, a temporary suspension of travel by in-bound workers was imposed on the Ranger mine, and at Olympic Dam, measures were implemented across the operation to reduce virus risk. Work restrictions have since been eased but at the time of writing, it is not clear how COVID-19 pandemic induced work restrictions on mining and milling will impact future uranium production and further disruption caused by the pandemic could ripple through the industry, constricting global supply of mined uranium.

In 2021, Kazatomprom announced that it planned to continue its market-centric strategy and discipline by maintaining 2023 production at a similar level to 2022, which is expected to be 20% lower than the planned volumes under its Subsoil Use Contracts. It also indicated that it does not expect to return to full Subsoil Use Contract production levels until a sustained market recovery is evident (Kazatomprom, 2021). In early 2022, Cameco announced that it intended to gradually resume production at the McArthur River mine and Key Lake mill by 2024, but at 40% below the annual licensed capacity of the operations (Cameco, 2022).

Present status of uranium production

North America

North American production of 3 886 tU amounted to 8% of world production in 2020, as production declined by 3 387 tU (47%) since 2018. This decrease is due to production cuts implemented because of an oversupplied market and COVID-19 work restrictions in Canada, and reduced competitiveness of US production in an oversupplied, low-price market during a lengthy period.

Canada lost its standing as the world's largest producer in 2009 due to production increases in Kazakhstan, and although it remains the dominant North American producer, it dropped from second to the world's fourth-largest producer in 2020, behind Australia and Namibia. Current Canadian uranium production is well below the full licensed production capacity of over 25 000 tU at the existing uranium mills. Production in 2020 was 3 878 tU (its lowest level since 1975), 44% below 2019 production of 6 944 tU, as operations were suspended for six months due to the COVID-19 pandemic. The Cigar Lake mine and McClean Lake mill were returned to production in April 2021. Operations at the McArthur River mine and Key Lake mill have been suspended since January 2018 in response to low uranium market prices and Canadian production will increase further when operations at McArthur River and Key Lake resume.

McArthur River mine has remaining identified recoverable resources of 154 100 tU with an average grade of 5.5% U. The Key Lake mill, also idled, recovered 61 tU from cleaning the mill circuits in 2018 and 6.1 tU in 2019, but there was no uranium produced at the mill in 2020.

The Rabbit Lake production centre was idled in mid-2016 due to low uranium prices and the facility was placed in care and maintenance. Exploratory drilling at the Eagle Point mine during the last several years has increased identified resources to 27 000 tU at an average grade of 0.63% U.

The Cigar Lake mine, with recoverable resources of 111 100 tU at an average grade of 11% U, was the world's largest producing uranium mine in 2019. However, production decreased by 44% in 2020 due to the COVID-19 pandemic. The McClean Lake mill produced 6 938 tU and 3 878 tU from Cigar Lake ore in 2019 and 2020, respectively. In December 2020, Orano purchased the 7.5% share of the McClean Lake production centre that was held by Overseas Uranium Resources Development (Canada) Co. Ltd, a subsidiary of Overseas Uranium Resources Development Corporation of Japan.

In February 2022, Cameco announced that it planned to restart the McArthur River mine and Key Lake mill in 2024, operating at reduced capacity, in line with the company's supply discipline strategy that will continue until the uranium market improves and Cameco has signed long-term contracts for its in-ground inventory of uranium. In 2024, it plans to produce 15 million lbs U_3O_8 (5 770 tU) at McArthur River/Key Lake, 40% below the annual licensed capacity of the operation, and 13.5 million lbs U_3O_8 (5 190 tU) at Cigar Lake, 25% below its annual licensed capacity. Total planned production in 2022 continues to face risks due to the ongoing COVID-19 pandemic and related global supply chain disruptions, including at Cigar Lake, where 15 million pounds U_3O_8 (5 770 tU) are expected to be produced, which is 20% below the facility's licensed capacity (Cameco, 2022).

Uranium mines in the United States produced 67 tU in 2019, 76% less than in 2018 (277 tU). Data on 2020 production were withheld because of the limited number of companies actively mining. Production in 2019 came from seven facilities: six ISR plants in Nebraska and Wyoming (Crow Butte Operation, Lost Creek Project, Ross CPP, North Butte, Nichols Ranch, and Smith Ranch-Highland Operation) and one underground mine. When mined, uranium ore from underground mining is stockpiled and eventually shipped to the White Mesa Mill for milling into U_3O_8 concentrate.

In March 2022, the EIA reported that in the last quarter of 2021, a total of 9 978 lbs U_3O_8 (3.8 tU) had been produced from three facilities in the United States: Nichols Ranch (ISL), the Ross central processing plant and the Crowe Butte operation in Nebraska, up 88% from the third quarter production of 5 297 lbs U_3O_8 (2.0 tU). No uranium was produced in the first two-quarters of 2021 (EIA 2022). This information, although not complete, suggests that uranium production had declined to as low as 8 tU in 2020 and 4 tU in 2021.

At the end of 2020, the Lost Creek and Smith Ranch-Highland in situ recovery (ISR) operations in Wyoming were operating with a combined theoretical (nominal) annual capacity of 7.5 million pounds of U_3O_8 (2 900 tU). Nine ISR plants were on standby at the end of 2020, and nine ISR plants were planned throughout four states: New Mexico, South Dakota, Texas and Wyoming. One uranium mill (White Mesa in Utah) was operating with a capacity of 1 814 metric tonnes of ore per day. During 2019, the White Mesa Mill did not produce any uranium. In 2020, White Mesa produced about 70 tU from reprocessed on-site pond water and alternative feed material. Alternative feed material includes uranium extracted during municipal water treatment, process residues from uranium conversion, uranium-bearing tails from other metal recovery operations, and others. Two mills (Shootaring Canyon in Utah and Sweetwater in Wyoming), with a combined capacity of 3 402 metric tonnes of ore per day, remained on standby status. Both mills have been on standby status since the early 1980s and will require rehabilitation to operate again.

The United States has a number of conventional and ISR-amenable mines and deposits with some degree of permitting or development. Most of these are indefinitely paused, awaiting more favourable market conditions. ISR mining and exploration is mostly conducted in Texas and Wyoming, and conventional mine-related activity is in the part of the Colorado Plateau that includes Colorado, Utah, New Mexico and Arizona.

Many uranium mining and exploration companies were hopeful that supportive recommendations would emerge from the Nuclear Fuel Working Group established in July 2019, in response to a Section 232 Petition from two United States uranium miners. On 23 April 2020, the United States Department of Energy released the Administration's Nuclear Fuel Working Group strategy with recommendations to revitalise and strengthen the front end of the nuclear fuel cycle and the domestic nuclear industry. One of the recommendations of this group was to create a national strategic uranium reserve from domestically produced uranium over a ten-year period. In December 2020, a United States federal budget was enacted that included the first year of funding for developing this uranium reserve. DOE will administer the USD 150 million/year plan, which is slated to buy uranium directly from domestic mines and support domestic conversion operations. These developments, along with increased uranium market prices, have led to US uranium producers reportedly making plans to increase production from facilities in Wyoming and Utah by improving efficiencies, as well as accelerating development of other properties (WNA, 2022b). Geopolitical tensions in eastern Europe can be expected to further incentivise domestic uranium production.

South America

There has been no uranium production in South America since 2015, except for 30 tU produced during the commissioning process for mining the Engenho deposit in Brazil in 2021. Work continues in Argentina to restart production at the Sierra Pintada mine and to develop a new production centre for the Cerro Solo deposit. In Brazil, the licensing process to mine the remainder of the Cachoeira deposit (Lagoa Real) by underground methods is under way, and the expansion of the Lagoa Real, Caetité unit to 670 tU/year is also progressing, including commissioning of the Engenho deposit, with completion expected in 2027. Development of the Santa Quitéria phosphate/uranium project remains in progress, with production currently scheduled to begin in 2024.

In Argentina, domestic uranium requirements are increasing as the country's nuclear generating capacity is increasing, incentivising domestic production. However, regulatory and environmental issues remain to be addressed before uranium production can resume. In 2018, the 2013 update of an environmental impact assessment (EIA) for restarting production at the San Rafael mining-milling complex (Sierra Pintada mine) was presented to provincial authorities, who reached a favourable technical opinion, and a mandatory public hearing was held in 2019 with positive outcomes, resulting in provincial authorities approving the EIA.

However, before restarting uranium production at San Rafael, it will also be necessary to obtain both provincial approval and agreement to amend the provincial law that prevents the use of sulphuric acid and other chemicals that may be used in the operation. Technical feasibility has been partially demonstrated by the fact that this deposit was previously in operation, using the acid heap leach processing method. However, other alternatives have been considered for possible future production, including the use of alkaline leaching, bioleaching and vat leaching. Also, given the possibility of reopening the mining-milling complex, all available data have been processed to refine the geological model and formulate more suitable mining and processing.

CNEA continues developing feasibility studies for the proposed mining of the Cerro Solo deposit (Chubut Province) and several laboratory-scale tests have been carried out to determine the most economically competitive milling process, including possible by-product molybdenum production. The project has been placed on standby because, in addition to technical considerations, a provincial law preventing open-pit mining remains in effect and a provincial regulatory framework for mining needs to be developed.

Until 2021, no production had been reported in Brazil following mining of the entire open-pit portion of the Cachoeira deposit (Lagoa Real, Caetité) in 2014, until the commissioning process of the Engenho deposit began in Brazil in 2021. Both the licensing process to mine the remainder of the Cachoeira deposit by underground methods and resource reassessments are under way, with full scale expanded production expected to begin in 2027.

The expansion of the Lagoa Real, Caetité unit to 670 tU/year is also progressing, with completion expected in 2027. The expansion involves replacement of the heap leaching process by conventional agitated leaching and an overall investment estimated to amount to USD 90 million.

Since 2014, Industrias Núcleares do Brasil S.A. (INB) has been working on the development of the Engenho deposit, with the commissioning process beginning in 2019-2020 without significant production. Mine production amounted to 30 tU in 2021. Initially, Engenho was planned as an additional ore source for increased production at the Caetité plant, but it is currently the only source of ore for the mill due to the delay in commissioning the Cachoeira underground mine.

Development of the Santa Quitéria phosphate/uranium project, under the terms of an INB-Brazilian fertiliser producer partnership agreement, remains in progress. In 2012, the project operators applied for a construction licence that was denied in 2018. INB and its partner worked on a new model for the project and a revised licence application was filed in 2020, with a decision expected in 2022. The operation is currently scheduled to begin in 2024.

European Union

Primary uranium production in the European Union (EU) for 2020 was from only one country, the Czech Republic, which produced 28 tU by ISL. Total reported EU production in 2020 was 44 tU, an increase of 13% from the 39 tU reported for 2018. With the end of mining at Rozná in the Czech Republic in 2017, and a new law enacted in 2021 that ends the issuance of new permits for exploitation of radioactive mineral deposits in Spain, EU production should continue to decline as uranium recovery from mine remediation declines as remediation proceeds.

The Czech Republic also recovered 6 tU in ongoing mine water treatment in remediation activities, while Germany and Hungary contributed 7 tU and 3 tU, respectively, from mine remediation activities only. France had also been producing minor amounts as a by-product of mine remediation activities but reported no uranium production in this fashion from 2018 to 2021. In Germany, where all uranium production since 1992 has been from remediation activities at the Königstein mine, uranium will no longer be separated and recovered owing to the decreasing content of uranium and heavy metals in the flood waters in recent years.

Europe (non-EU)

Output from non-EU countries in Europe in 2020 amounted to 3 557 tU, a 4% decrease from 2018. Production declined in Russia by 58 tU and in Ukraine by 79 tU over this two-year period.

Production by non-EU countries in Europe in 2020 accounted for about 8% of total global production.

In 2020, uranium production in Russia, carried out by three enterprises that are part of the uranium mining company Uranium Holding ARMZ (JSC Atomredmetzoloto), amounted to 2 846 tU, of which 1 240 tU was obtained by traditional underground mining at Priargunsky (120 tU of this total by heap leaching) and 1 606 tU by ISL. Since 2018, uranium production in Russia by underground mining has decreased by 15%, whereas ISL production has increased by 11%.

During 2018-2020, construction of the Mine No. 6 surface complex and infrastructure elements continued at Priargunsky (design capacity of 2 300 tU/yr) for the development of the Argunskoye and Zherlovoye deposits, with the start of mining scheduled for 2026. ISL uranium mining of deposits at the Khiagda ore field (recoverable resources of 25 133 tU) in the Republic of Buryatia by JSC Khiagda continued and, in 2020, development of the Kolichikan deposit (6 530 tU RAR) and the Dybryn deposit (6 634 tU RAR) began, with mining expected to begin in 2021 and 2023, respectively. In addition, JSC Dalur (Kurgan Oblast) started preparations for pilot uranium mining at the Dobrovolnoye deposit in 2020. Development of deposits in the Elkon uranium region has been suspended due to unfavourable market conditions.

In Ukraine, 2020 production amounted to 711 tU (623 tU by conventional mining and 88 tU by heap leaching), all of which was produced at three underground mines located in the central Ukrainian ore province (Ingulska, Smolinska and Novokostyantynivska). Production in 2020 declined by 10% from 790 tU in 2018 and was expected to decline more sharply to 455 tU in 2021. Long-term government plans include mining the Safonivske deposit by ISL (ISL operations were conducted from 1966 to 1983 at the Devladovske and Bratske deposits that are now being monitored after decommissioning), as well as developing the Severinskie and Podgaytsevske deposits for underground mining. The Energy Strategy of Ukraine to 2035, which was approved by government in 2017, set a target that all uranium requirements for the Ukrainian nuclear fleet must be met entirely by domestic production, up from the 30% of requirements produced domestically in 2020.

Africa

African production decreased by 3%, from 8 744 tU in 2018 to 8 465 tU in 2020, accounting for about 18% of global production. Production in Namibia continued to rise as the Husab operation moved closer to full production capacity and production at Rössing increased in recent years. However, the Rössing mine is scheduled to close at the end of 2026. Norasa, Etango and other projects under development would more than compensate for the upcoming Rössing closure, should they be successfully brought into production. In Niger, production amounted to just under 3 000 tU in 2019 and 2020 as production at the Somaïr (Arlit) open-pit mine has been lowered by 30% since 2015 due to weak market conditions. On 31 March 2021, due to the exhaustion of ore and high operating costs, Cominak's Akouta mine ceased production after nearly 50 years of service. Production in South Africa declined from 346 tU in 2018 to 62 tU in 2020 as depressed market conditions and COVID-19 work restrictions limited production, but production is expected to increase to 192 tU in 2021.

In 2020, Lotus Resources Ltd (the new owner of the idled Kayelekera mine in Malawi), conducted a restart scoping study of the uranium production centre. Two scenarios were considered: treating only high grade material and treating the medium-grade stockpiles at the end of the life of mine after high grade material is exhausted. The restart of Kayelekera is expected to require an initial capital cost of USD 50 million, but no target date for the restart was specified.

Total uranium production in Namibia reached 3 593 tU in 2016 and increased to 4 221 tU in 2017 and 5 520 tU in 2018. Start-up of the Husab mine is the main reason for these production increases. In 2020, uranium production in Namibia amounted to 5 412 tU, 3 301 tU of which was produced at Husab and 2 111 tU at Rössing. Production at the open-pit Husab mine reached 1 140 tU in 2017, was ramped up to 3 026 tU in 2018 and maintained at a level 3 300 to 3 400 tU during 2019 and 2020. The Husab mining fleet will need to move 15 million tonnes of ore per year from two separate open pits to feed a processing plant to produce the nameplate capacity of 5 700 tU per year. In 2019, Rio Tinto plc sold its 69% share of Rössing to the China National Uranium Corporation, a wholly owned subsidiary of the government-owned China National Nuclear Corporation. Production at Rössing Uranium has steadily increased over the last few years as the mine has accessed higher-grade ore after the Phase 2 and 3 pushbacks and production levels increased gradually to 2 111 tU in 2020. The higher-grade material does, however, come with increased calcium content, thereby limiting processing plant throughput. To process the higher calcium carbonate containing ores, the annual capacity of the processing plant was reduced to 9.2 million tonnes per annum. The current mine plans foresee a cessation of Rössing production at the end of 2026. However, both the idled Langer Heinrich and Trekkopje production centres, as well as projects under development, are poised to begin production with improved market conditions.

Production in Niger totalled 3 484 tU in 2017 and 2 878 tU in 2018, then increasing slightly to 2 982 in 2019 and 2 991 tU in 2020. In 2019, Somaïr's Arlit open-pit mine produced 1 912 tU and Cominak produced 1 070 tU at the Akouta underground mine. Production in 2020 amounted to 2 991 tU, of which 1 879 tU were produced by Somaïr and 1 112 tU by Cominak. Production at the Arlit open-pit mine has been lowered by 30% since 2015 due to weak market conditions but it is expected to continue operating until the late 2020s as additional resources have been added over the last few years. On 31 March 2021, due to the exhaustion of ore and high operating costs, production at Cominak's Akouta mine was brought to a halt with cumulative production from 1978 to the end of 2020 amounting to approximately 75 000 tU. It is expected that uranium production in Niger will decrease by about 25% due to the Akouta mine shutdown from 2021 on until mines under development in the country, such as Imouraren, Dasa and Madouela, are brought into production.

Production in South Africa declined from 346 tU in 2018 to 62 tU in 2020 but increased to 192 tU in 2021 as COVID-19 work restrictions were lifted. However, depressed market conditions continue, making most operations in the country uneconomic, and production is limited. In 2019 and 2020, uranium production came from the Harmony Gold Vaal River operation (Moab Knotsong mine). At the end of March 2020, the government imposed a 21-day lockdown in response to the COVID-19 pandemic. As part of the lockdown, all mining operations (apart from coal mines supplying Eskom) were initially suspended, then in mid-April 2020 they were allowed to resume mining at up to 50% of normal capacity. Most of South Africa's historical uranium production was derived from quartz-pebble conglomerate deposits (a by-product of gold or, to a minor extent, copper) with a small proportion from the Palabora copper-bearing carbonatite. Current production is sourced from the quartz-pebble conglomerate deposits and associated tailings. Future production centres could include the Dominion Reef mine and Beaufort West deposit (Karoo Basin).

The Witwatersrand Basin contains about 79% of total identified uranium resources in South Africa, in both the underground, hosted by quartz-pebble conglomerates, and their resulting tailings storage facilities. Approximately 47% of the total national identified resources are in the Witwatersrand underground operations, 28% in their associated tailings facilities, 20% in the Springbok Flats Basin, and about 5% in the sandstone-hosted deposits of the Karoo Basin. The uranium pay limit in most parts of the Witwatersrand Basin is calculated on a by-product basis, according to which the uranium is not classified as a resource unless it occurs in an area of gold mineralisation that satisfies the estimated gold cut-off grades. In addition, uranium production in these projects only includes the costs of transporting ore from the underground or tailings operations to the processing plants and the treatment of uranium, while gold carries all other costs. The Witwatersrand Basin has a total of about 470 tailings storage facilities with uranium resources, most of which are not included in reasonably assured and inferred conventional resource totals. Should uranium market conditions improve, uranium contained in South African gold mine tailings could be recovered to help meet demand.

With improved market conditions uranium production in Africa could surge, as idled mines in Namibia (Langer Heinrich, Trekkopje) and Malawi (Kayelekera) could be returned to production in a relatively short time and mine development projects in Botswana (Letlhakane), Mali (Falea), Mauritania (Tiris), Namibia (Etango, Norasa, Marenica, Omahola, Wings), Niger (Dasa, Madaouela, Imouraen), Tanzania (Mkuju River) and Zambia (Mutanga) are poised to be brought into production, potentially providing significant production capacity. Development of many of these projects has been stalled due to poor market conditions and, in 2020 and 2021, work restrictions related to the COVID-19 pandemic.

Middle East, Central and Southern Asia

Production in the Middle East, Central and South Asia region declined by 8% from 25 605 tU in 2018 to 23 595 tU in 2020. This was driven principally by the world's largest producer, Kazakhstan, where production was decreased from 21 705 tU in 2018 to 19 477 tU in 2020 by planned production cuts. Despite this decline, Kazakhstan accounted for 41% of global production in 2020. India and Pakistan do not report production figures, but their combined total is estimated to be about 505 tU in 2019 and 585 tU in 2020. Neither Uzbekistan nor Iran provided information for this report, but production in 2019 and 2020 is estimated to have amounted to 3 500 tU/yr in Uzbekistan (maintaining its position as the world's fifth largest producer) and 21 tU/yr in Iran.

India continues to ramp up production capacity after commissioning the Tummalapalle mill in January 2017, with plans to increase capacity at both the Tummalapalle and Turamdih mills from 3 000 to 4 500 t/day ore. However, the country does not report either production or production costs and the effect of increasing mill input on production is uncertain. In April 2022, it was reported that over the past three years, India has imported a total of 4 557.67 tU from Kazatomprom and 2 988.37 tU from Cameco, all as natural uranium ore concentrate. It also imported 56.78 tU from TVEL, in the form of enriched uranium fuel pellets, with all imports from Russia taking place during 2019 and 2020 (WNA 2022c).

Jordan does not produce uranium but continues developing resources with the aim of doing so, working on production from surficial deposits in central Jordan as well as extracting uranium from phosphates. In 2021, a pilot-scale uranium extraction plant was commissioned to fine-tune the developed process for extracting uranium from the local ores in central Jordan and to generate the technical data needed to finalise the detailed engineering of a commercial plant. Mutual collaboration between Jordan and the IAEA enabled the establishment of on-site analytical laboratories in 2020 to support exploration and extraction activities.

In Kazakhstan, all uranium was produced by the ISL method. In 2019 and 2020, uranium was mined at the Kanzhugan, Moinkum, Akdala, Uvanas, Mynkuduk, Inkai, Budenovskoye, North and South Karamurun, Irkol, Zarechnoye, Semizbay, Northern Kharasan deposits. With the largest share (64%) of the world's low-cost (<USD 40/kgU) resource base, with 95% of all identified uranium resources associated with existing and committed production centres and 27 000 tU/yr of production capacity, Kazakhstan can be expected to remain the world's largest producer for the foreseeable future. On 2 July 2021, Kazatomprom announced that it planned to continue its market-centric strategy and discipline by maintaining 2023 production at a similar level to 2022, which is expected to be 20% lower than the planned volumes under its Subsoil Use Contracts and does not expect to return to full Subsoil Use Contract production levels until a sustained market recovery is evident, supply and demand conditions signal a need for more uranium, and the company's pipeline of mid- to long-term contract negotiations implies that there is a low risk of produced volumes further delaying the recovery (Kazatomprom, 2021).

Uzbekistan has produced uranium since 1946 and conducted the first ISL tests in 1968. Since 1995, Uzbekistan has been producing uranium using only ISL technology and has developed and implemented two new technologies of acid ISL for ores with high carbonate content. The first, a bicarbonate–acid method that is used for ores with a carbonate content above 2%, reduces repair and restoration procedures for plugged wells by 2.5-3 times. The second uses a mini-reagent technology that is applied to ores with a carbonate content >0.5% located in artesian aquifers. Implementation of these two technologies has significantly reduced acid consumption and in turn operating costs by 20-30%.

Uranium produced in Uzbekistan since 1992 has mainly been exported to China, India, South Korea and the United States. In May 2014, China's CGN agreed to buy USD 800 million of uranium through to 2021. Uzbekistan's state-owned Navoi Mining and Metallurgy Combinat (NMMC) has also signed a contract to supply 2 000 tU to India from 2014 through 2018. In December 2019, Uzbekistan agreed to sell uranium to two Japanese trading companies. Uzbekistan's NMMC signed separate contracts with ITOCHU (valued at USD 636.4 million) and Marubeni (valued at USD 510.1 million), with both agreements covering uranium deliveries between 2023 and 2030. From 2015 to 2020, Uzbekistan has maintained an annual production of approximately 3 300 tU to 3 500 tU.

East Asia

China, the only producing country in East Asia, reported variable production from 1 650 tU in 2016 to 1 580 tU in 2017 and 1 620 tU in 2018 as the country transitions from higher cost underground mines, mainly in the south, to lower cost ISL production centres in the north. However, because production figures were not reported by China for 2020 and 2021, the Secretariat assumes that production has remained steady at 1 600 tU/yr.

In response to the challenges brought about by sustained low uranium prices and efforts to meet ecological goals set by the government of China, state-owned Chinese uranium companies were reorganised in 2017 and 2018. Of the three hard-rock, underground uranium mines with depleted uranium resources or with high production costs, one (Qinglong) was closed for decommissioning and operations at two others (Chingyi, Lantian) were idled. With improved uranium market conditions, the idled uranium production centres are expected to be brought back into operation. The uranium industry's focus of production has become dominated by ISL mining in northern China, supplemented by underground mining in southern China, and the principal exploration effort has shifted to ISL. ISL production capacity was expanded at the Yining centre in the Xinjiang Autonomous Region (north-west China) and the Tongliao centre in Inner Mongolia (north-east China), but the level of capacity after these expansions is unknown.

Pacific

Australia is the only producing country in the Pacific region. Production remained relatively steady at 6 526 tU in 2018 and 6 613 tU in 2019, before declining to 6 195 tU in 2020. However, only 3 817 tU are expected to be produced in 2021 as the Ranger mine ceased production on 8 January 2021. Mining at Ranger Pit 3 concluded in December 2012, but stockpiled ore continued to be processed at the main metallurgical plant and the laterite treatment plant until operations ceased. The Gundjeihmi Aboriginal Corporation advised the mine operator and owners in 2016 that the Mirarr Traditional Owners do not support the creation of a new Ranger Authority, which would have provided the regulatory mechanism to enable mining after 2021. Rehabilitation activities at the Ranger site have commenced and are scheduled to be completed by January 2026. Since operations began in 1981, more than 132 000 tonnes of uranium oxide concentrate (112 000 tU) were produced at the Ranger mine.

Australia currently has five approved uranium mines, all in South Australia: Olympic Dam, Honeymoon, Beverley, Beverley North and Four Mile, with only Olympic Dam and Four Mile producing uranium in 2020. Plans for a large expansion at Olympic Dam have been scaled back and although BHP plans for production to remain stable in the near term, it is anticipated that output could increase over time through incremental production efficiency gains and infrastructure investment. Mining at Beverley and Beverley North has now ceased and is currently working towards closure. Honeymoon (Boss Energy) has been idled with all government approvals in place, and in June 2022 the company announced a final investment decision to develop the project. Four uranium mining projects, all in Western Australia and all with government approvals to proceed are also awaiting improved market conditions for further development: Kintyre and Yeelirrie (Cameco Australia Pty Ltd), Wiluna (Toro Energy Ltd), and Mulga Rock (Vimy Resources Ltd). If Honeymoon and all four projects under development are successfully brought into production, annual production capacity in Australia will increase by 8 000 tU.

Ownership

Table 1.19 shows the ownership of uranium production in the 17 countries that produced uranium in 2020 and Brazil, which did not produce in 2020, but has produced recently. Ownership of production in 2020 has not changed since 2018. Domestic mining companies continued to control about 56% of production in 2020, as in 2018. Domestic government participation increased from 37% in 2016 to 42% in 2018, owing to increased shares in Kazakhstan and Namibia, whereas the share of domestic private companies declined from 18% in 2016 to 14% in 2018, as an increased share in Australia offset a decline in Canada. Non-domestic mining companies continued to control about 44% of production in 2020 (no change from 2018). It should be noted that for this reporting period, the percentage of control (i.e. government vs. private) of non-domestic mining companies, for both Australia and the United States, is not reported.

Table 1.19. **Ownership of uranium production**

(as of 1 January 2021, based on 2020 production output)

Country	Domestic mining companies				Non-domestic mining companies				Total
	Government-owned		Privately-owned		Government-owned		Privately-owned		
	tU	%	tU	%	tU	%	tU	%	tU
Australia[1]	0	0	3 226	52	2 969	48	0	0	6 195
Brazil	0	0	0	0	0	0	0	0	0
Canada	0	0	1 939	50	1 435	37	504	13	3 878
China*	1 600	100	0	0	0	0	0	0	1 600
Czech Republic	34	100	0	0	0	0	0	0	34
Germany	7	100	0	0	0	0	0	0	7
Hungary	3	100	0	0	0	0	0	0	3
India*	540	100	0	0	0	0	0	0	540
Iran, Islamic Rep of*	21	100	0	0	0	0	0	0	21
Kazakhstan	10 712	55	0	0	6 038	31	2 727	14	19 477
Namibia	402	7	0	0	4 957	92	53	1	5 412
Niger*	1 032	35	0	0	1 570	53	389	13	2 991
Pakistan*	45	100	0	0	0	0	0	0	45
Russia	2 846	100	0	0	0	0	0	0	2 846
South Africa*	0	0	62	100	0	0	0	0	62
Ukraine	711	100	0	0	0	0	0	0	711
United States*	W	W	8	100	0	0	W	W	8
Uzbekistan*	3 512	100	0	0	0	0	0	0	3 512
Total	21 465	45	5 235	11	16 969	36	3 673	8	47 342

* Secretariat estimate. 1. Government and Private Non-domestic ownership of uranium production not separated. W = Data withheld to avoid disclosure of individual company data.

Employment

Although the data are incomplete, Table 1.20 shows that employment levels at existing uranium production centres declined by 10% from 2018 to 2020, owing to gradually declining employment reported by some key countries, including Australia and no officially reported employment figures for Namibia, Niger and the United States. Preliminary employment figures for 2021 suggest that mine employment is expected to decline more dramatically, but this is mainly due to data not being reported for Canada and Kazakhstan.

Table 1.20. **Employment in existing production centres**

(as of 1 January 2021, for listed countries, person-years)

Country	2014	2015	2016	2017	2018	2019	2020	2021 (preliminary)
Argentina[a]	85	82	65	58	54	55	51	52
Australia[b]	5 805	4 481	3 630	4 488	4 559	3 198	3 134	2 738
Brazil	620	590	680	680	500	550	550	550
Canada[c]	2 874	2 676	2 246	1 418	1 844	1 824	1 934	NA
China	7 660	7 670	6 750	5 950	2 350	2 290	2 300*	2 300*
Czech Republic	2 072	2 040	1 955	1 672	1 557	1 556	1 546	1 550
Germany[a]	1 147	1 062	1 043	1 031	1 010	982	911	857
India	4 689	4 725	4 741	4 722	4 629	4 672	4 630	4 600
Iran, Islamic Rep of	500	350	340	290	280*	280*	280*	280*
Kazakhstan[d]	7 728	8 042	8 222	25 224	20 801	20 684	21 186	NA
Namibia[e]	5 101	8 107	4 331	4 881	NA	NA	NA	NA
Niger*	NA	NA	3 935	3 843	3 011	NA	NA	NA
Russia	8 790	6 857	6 077	5 696	6 263	6 163	6 103	6 179
South Africa	4 141	3 815	NA	NA	NA	NA	NA	NA
Spain[f]	23	21	76	78	79	79	42	42
Ukraine	4 500	4 555	4 426	4 450	4 275	3 701	3 741	3 829
United States	626	509	462	324	234	155	W	NA
Uzbekistan	NA	NA	NA	NA	NA	NA	NA	NA
Total	56 361	55 582	48 979	64 805	51 446	46 189	46 408	22 977

(*) Secretariat Estimate. NA = Data not available. W = Data withheld to avoid disclosure of individual company data. (a) Employment related to decommissioning and mine rehabilitation only. (b) Olympic Dam does not differentiate between copper, uranium, silver and gold production. Employment has been estimated for uranium-related activities. (c) Employment at mine sites and head offices. (d) Total number of Kazatomprom employees reported from 2017 onward. (e) Peak in 2015 due to Husab mine construction. (f) Employment related to decommissioning and rehabilitation only from 2012 to 2015, but includes employment related to mine development activities from 2016 to 2021.

However, if future production expansions and restarts of mines currently in care and maintenance in countries such as Australia, Canada, China, India, Kazakhstan, Namibia, Niger, Russia, the United States and others are successfully completed, employment should increase in the longer term. However, because ISL production centres in China are highly automated, employment in China's uranium production sector may not recover to pre-2018 levels as ISL, now the favoured domestic method of production, requires fewer employees than underground mines.

Table 1.21 shows employment directly related to uranium production (excluding head office, research and development, pre-development activities, etc.) in selected countries. Figures show generally declining or relatively static employment as global production decreased. Declining employment was most pronounced in Canada and Kazakhstan as temporary production cuts were implemented.

Table 1.21. **Employment directly related to uranium production and productivity**

(as of 1 January 2021, for listed countries)

Country	2018		2019		2020	
	Production employment (person-years)	Production (tU)	Production employment (person-years)	Production (tU)	Production employment (person-years)	Production (tU)
Australia[(a)]	3 163	6 526	2 200	6 613	2 175	6 195
Brazil	310	0	310	0	350	0
Canada[(b)]	831	6 996	913	6 944	746	3 878
China	1 490	1 620	1 500*	1 600*	1 500*	1 600*
Czech Republic	786	34	806	42	793	34
Iran, Islamic Rep of	95	20	95*	21*	95*	21*
Kazakhstan	7 822	21 705	7 242	22 808	7 060	19 477
Namibia	2 585	5 520	3 231	5 477	3 319	5 412
Niger*	1 478	2 878	NA	2 982	NA	2 991
Russia	4 601	2 904	4 726	2 911	7 060	2 846
South Africa	NA	346*	NA	185*	NA	62*
Ukraine	1 490	790	1 288	796	1 332	711
United States	207	277	NA	67	NA	8*
Uzbekistan*	7 340	3 450	7 387	3 500	7 500	3 512
Total	32 198	53 066	29 698	53 946	31 930	46 747

(*) Secretariat estimate. (a) Olympic Dam does not differentiate between copper, uranium, silver and gold production. Employment has been estimated for uranium-related activities. (b) Employment at mine sites only.

Production methods

Historically, uranium has been produced mainly using open-pit and underground mining techniques, then processed by conventional uranium milling. Other mining methods include ISL (sometimes referred to as ISR); co-product or by-product recovery from copper, gold and phosphate operations; heap leaching and in-place leaching (also referred to as stope or block leaching). Stope/block leaching involves the extraction of uranium from broken ore without removing it from an underground mine, whereas heap leaching involves the use of a leaching facility on the surface after the ore has been mined. Small amounts of uranium are also recovered from mine water treatment and environmental restoration activities.

Over the past two decades, ISL mining, which uses either acid or alkaline solutions to extract the uranium directly from the deposit, has become increasingly important. The uranium dissolving solutions are injected into and recovered from the ore-bearing zone using a system of wells. ISL technology is currently being used to extract uranium from sandstone deposits only and in recent years has become the dominant method of uranium production.

The distribution of production by type of mining or "material sources" for 2018 through 2021 is shown in Table 1.22. The category "other methods" includes recovery of uranium through the treatment of water recovered during reclamation and decommissioning activities, and more recently has also included production from refinery wastes and cleaning mill circuits in Canada.

ISL technology continues to dominate uranium production, largely because of the rapid growth of this low-cost method of production in Kazakhstan, and to a lesser extent in Australia, China, Russia and Uzbekistan. Note that not all countries report production by method, and for this reporting period, the United States, where most production is by ISL, the information is not officially reported. World uranium production by ISL amounted to 55.5% of total global production in 2018, increasing 63.3% in 2021, owing to expected ISL production increases principally in Australia, China, Kazakhstan and Russia. The decreasing share of underground mine production over this reporting period is mainly driven by decreases in Canada due to temporary production cuts and in Niger due to the closure of the Cominak mine, and to a lesser extent in Russia and Ukraine.

Table 1.22. **World production by production method**

(as of 1 January, 2021, percent)

Production method	2018	2019	2020	2021 (preliminary)
Open-pit mining	17.0	16.6	18.7	17.1
Underground mining	20.8	19.9	16.1	15.1
ISL	55.5	56.9	58.3	63.3
In-place leaching	0	0	0	0
Co-product/by-product	6.6	6.5	6.6	4.5
Heap leaching	0	0	0	0
Other[(a)]	0.1	0	0	0
Total	100	100	100	100

(a) 61 tU recovered from cleaning Key Lake (Canada) mill circuits in 2018.

Projected production capabilities

To assist in developing projections of future uranium availability, member countries were asked to provide projections of *production capability* through 2040 (Table 1.23). Projections for 2025 to 2040 are included for *existing and committed production centres* (A-II columns) and for *existing, committed*, *planned and prospective production centres* (B-II columns) in the <USD 130/kgU category for countries that are either currently producing uranium or have plans and the potential to do so in the near future. Note that both the A-II and B-II scenarios are supported by currently identified local RAR and IR in the <USD 130/kgU category, except in Pakistan. Also note that actual production seldom, if ever, matches full production capability.

Several current or potential uranium producing countries including Argentina, Botswana, China, India, Mauritania, Mongolia, Namibia, Niger, Pakistan, South Africa, Tanzania, Ukraine, the United States, and Uzbekistan did not officially report, or only partially reported, projected production capabilities to 2040. In some countries, the NEA/IAEA suggested updates to the submitted data to include recent and important changes since the cut-off date for data submission. As a result, estimates of production capability for many countries were developed by the NEA/IAEA using data submitted for past Red Books, company reports and other public data.

The reported projected production capabilities for existing and committed production centres for 2025 are 69 675 tU in the A-II category and 83 105 tU in the B-II category, a decrease of 7 750 tU in the A-II category and an increase of 1 495 tU in the B-II category compared to 2025 production capability estimates reported in the 2020 edition of this report. Increased production capability will likely not translate into increased production in the early 2020s because, as of May 2022, uranium production was significantly below full production capability as mining was temporarily suspended in some important producing countries and workforce limitations and work practice adjustments were implemented in response to the COVID-19 pandemic.

Projections beyond 2025 show generally decreasing global production capabilities as A-II category estimates decline in response to depletion of resources at existing and committed production centres. In contrast, B-II production capability generally increases through to 2040 due to the development of several projects that are ready to produce with improved market conditions, particularly in Australia, Canada, Namibia and Niger. Only Brazil, Canada, Kazakhstan and Russia reported production capability to 2040; the remaining projections to this date are NEA/IAEA estimates. These 2040 estimates show a decline in production capability from 2035 due to depletion of local resources (RAR and IR) available at <USD 130/KgU. Neither India nor Pakistan report production costs and these costs are considered high, likely above the cost threshold above, but because domestic uranium production is carried out in these countries without major considerations for the cost of production, projections for India and Pakistan are included in Table 1.23.

Table 1.23. **World production capability to 2040**

(as of 1 January 2021, tonnes U/year, from reasonably assured and inferred recoverable resources at costs up to USD 130/kgU)

Country	2025		2030		2035		2040	
	A-II	B-II	A-II	B-II	A-II	B-II	A-II	B-II
Argentina*	0	0	0	0	0	350	0	350
Australia	5 000	5 800	5 400	15 000	5 700	10 000	4 000	13 000
Botswana*	0	0	0	1 440	0	1 440	0	1 440
Brazil[(a)]	220	2 170	220	2 170	220	2 170	NA	1 950
Canada[(b)]	12 330	18 850	15 000	30 000	15 000	30 000	15 000	30 000
China*	1 800	2 000	2 000	2 400	2 000	3 000	1 500	3 500
Czech Republic[(c)]	50	50	50	50	30	30	20	20
Finland	0	250	0	250	0	250	0	250
Greenland[(d)]*	0	0	0	0	0	400	0	400
India[(e)]*	700	960	960	1 300	1 300	1 300	1 300	1 300
Iran, Islamic Rep of*	70	80	70	80	70	80	70	80
Kazakhstan	28 000	29 000	26 000	29 000	14 000	23 000	9 000	14 000
Malawi[(f)]	NA	NA	NA	NA	NA	NA	NA	NA
Mauritania*	0	0	0	315	0	315	0	315
Mongolia*	0	0	0	800	0	1 200	0	1 600
Namibia*	7 200	7 200	7 200	7 200	7 200	9 800	7 200	9 800
Niger*	1 700	1 700	1 700	4 100	4 100	7 400	7 400	7 400
Pakistan[(e)]*	45	45	45	45	45	45	45	45
Russia	2 700	2 700	2 300	4 100	1 600	3 500	1 500	2 400
South Africa*	1 160	3 000	1 160	3 000	1 180	2 800	1 090	2 500
Tanzania*	0	0	0	0	0	2 000	0	3 000
Ukraine*	1 000	1 200	1 500	1 700	1 500	1 700	1 000	1 700
United States[(g)]*	4 700	5 100	1 500	2 400	350	1 200	350	1 200
Uzbekistan*	3 000	3 000	2 000	2 500	800	2 500	0	2 000
Total	69 675	83 105	67 105	107 850	55 095	104 480	49 475	98 250

A-II = Production capability of existing, idled and committed centres supported by RAR and inferred resources recoverable at <USD 130/kgU. B-II = Production capability of existing, idled, committed, planned and prospective centres supported by RAR and inferred resources recoverable at <USD 130/kgU. * NEA/IAEA estimate. (a) BII category excludes Caetité expansion. (b) Projections consider McArthur/Key Lake operational by 2025. (c) Production from remediation. (d) 2021 legislation prohibiting uranium mining creates additional uncertainty for by-product U production in REE project under development. (e) Production costs not stated but considered high. (f) For Malawi, NA through 2040 because of uncertainty regarding legislation for mineral production and uranium market uncertainty (as reported in the Malawi country report). (g) For the United States, the projections consider the hypothetical case with all the existing and idled mines being operational in 2025.

Actual production seldom, if ever, reaches stated A-II production capability. In 2017, production was 85% of listed capability. From 2003 to 2015, production varied between 90% and 75% of listed production capability. From 2003 to 2011, the expansion of production capability was driven by increasing and what were considered sustainable uranium prices. Production also increased, although not as rapidly as the projected production capability. Since 2011, and despite a depressed uranium market, production continued to increase, mainly due to the start-up of the Cigar Lake mine in Canada, the continued expansion of production in Kazakhstan and the development of the Husab mine in Namibia. The fact that production increased during a period of depressed uranium market prices can be attributed to the long planning times and investment required to establish new mines and bring new production to the market, as well as the time it takes to respond to changing market conditions. Increasing global production since 2011 was essentially a response to increased demand and uranium market prices beginning almost a decade earlier. However, producers have recently responded to the sustained uranium market downturn by delaying mine expansions, temporarily shuttering some operations (e.g. McArthur River and Cigar Lake, Canada) and scaling back production at others (e.g. Kazakhstan), leading to declining global production since 2019. Turning stated production capability into production takes significant amounts of time, expertise and investment. Moreover, uranium mining operations and production plans can be confounded by unexpected geopolitical events, legal issues, technical challenges and so-called "Black Swan" events, the most recent being the COVID-19 pandemic and geopolitical tensions in eastern Europe.

Projections of production capability have increased somewhat compared to projections made in the 2020 edition of this report, as mine development activity has continued in key producing countries despite low market prices. Compared to the 2020 edition, category A-II and B-II projections for 2025 increased by 10% and decreased by 2%, respectively. Projections from 2030 to 2040 in the A-II category increased by 4.5% in 2030, 3.7% in 2035 and 13.2% in 2040, compared to projections made in the 2020 edition of this publication. Projections from 2025 to 2040 in the B-II category have increased by 34% in 2030, 25% in 2035 and 34% in 2040, compared to projections in the 2020 edition of this report. Compared to projections in earlier reports there are greater differences, which can be expected because of the continuous updating of plans and responses to market conditions, along with the amount of time it can take to respond to these changes.

As currently projected, production capability of existing and committed production centres (category A-II) is projected to reach about 69 675 tU by 2025, then decline by 4% to 67 105 tU in 2030, 18% to 55 095 tU in 2035, and 10% to 49 475 tU in 2040, with an overall decline of 29% from 2025 to 2040. The overall decrease of 29% in projected production capability from 2025 to 2040 reported in this edition reflects the general decline in local resources (RAR and IR) at existing and committed production centres.

Total potential production capability, including planned and prospective production centres (category B-II), is projected to reach about 83 105 in 2025, then increase to 107 850 tU in 2030, before declining to 104 480 tU in 2035 and 98 250 tU in 2040. The current projection estimates for B-II category production capability indicate an overall increase of 18% from 2025 to 2040, compared to a projected 10% decline over the same period reported in the 2020 edition of this report. This reflects the rate of mine development that has occurred in recent years despite the extended period of low uranium market prices continuing through mid-2021.

Recent committed mines and expansions

As expected during a prolonged period of low market prices and, more recently, planned production cuts at existing facilities, there were limited new production plans unveiled during this reporting period (Table 1.24). Since the first production from the Husab mine in Namibia in 2016, no new major developments have been completed and some have been delayed. However, it is now expected that by-product recovery of uranium from the Talvivaara deposit in Finland will begin in 2024. Kazakhstan remains committed to development of the Zhalpak deposit by ISL, but even though pilot production began in 2016, dates for completion and beginning production were not provided. In Russia, construction of the surface complex and infrastructure elements of new mine No. 6 at the Priargunsky production centre began in 2018. Completion, now scheduled for 2025, will increase annual production capacity of this operation by 2 300 tU.

Table 1.24. **Recent committed mines and expansions**

(as of 1 January 2021, nominal production capacity, tonnes U/year in parentheses)

Country	Production centre	2022	2023	2024	2025	2026	2027
Finland	Terrafame (Talvivaara)(1)			C (250)			
Kazakhstan	Ortalyk LLP (Zhalpak)(2)						
Russia	Priargunsky (Mine 6)				Exp (2 300)		

C = Committed. Exp = Expansion. 1) By-product of nickel, cobalt and zinc production. 2) Committed, but production capacity and start-up date not provided; pilot mining began in 2016.

There are few firmly scheduled additions to the existing and committed production capacities through 2027, suggesting that production may not be increased greatly through the addition of new facilities or the expansion of existing facilities through to 2027 as production cuts continue during the extended period of low market prices and major long-term producing mines in Australia (Ranger) and Niger (Cominak) were shut down in 2021.

Planned and prospective mines and expansions

An impressive list of planned and prospective mines could be brought into production through 2040 (Table 1.25), but as with existing and committed expansions in Table 1.24, few firm dates of completion have been provided and those that have are years away. The main increases in the longer term are expected to come from Australia, Botswana, Brazil, Canada, Kazakhstan, Namibia, Niger, Russia, Tanzania, Ukraine, the United States and Zambia. However, since few of these developments have a firm date for first production, most will not be developed until uranium market prices increase and remain at levels justifying the investments required to increase production.

With appropriate market signals, total annual production capacity could increase by as much as 75 000 tU by 2040 (Table 1.25). However, many of these increases in production capacity will only go forward if there are lasting improvements in market conditions, as the costs of mining and development of new exploitation technologies have increased and there are risks producing in jurisdictions that have not previously hosted uranium mining.

While there is uncertainty surrounding the development of prospective and planned production centres, given the depressed market conditions of recent years, the number of potential capacity additions listed in Table 1.25 underscores the availability of uranium deposits of commercial interest. Since these sites span several stages of approvals, licensing and feasibility assessments, it can reasonably be expected that at least some will take several years to be brought into production and others may never be. Notwithstanding the time it takes to bring new deposits into production, these new mine developments are timely since long-standing, significant production centres in Australia (Ranger) and Niger (Cominak) were closed in 2021, and the Rössing production centre in Namibia is expected to end production in 2026 (three facilities with a combined production capacity of 7 900 tU/yr).

Table 1.25. **Planned and prospective mines***

(as of 1 January 2021, nominal production capacity, tonnes U/year)

Country	Mine	tU/yr	Starting year
Argentina	Cerro Solo	200	2035
	Sierra Pintada	150	2035
Australia[(a)]	Yeelirrie	3 265	NA
	Kintyre	2 290	NA
	Mulga Rock	1 346	NA
	Wiluna**	527	NA
Botswana	Letlhakane	1 440	NA
Brazil	Santa Quitéria	1 950	2024
	Caetité/Cachoeira	340	2027
Canada	Arrow	11 155	NA
	Triple R	5 700	NA
	Kiggavik	3 000	NA
	Gryphon	2 900	NA
	Millennium	2 750	NA
	Midwest	2 300	NA
	Phoenix**	2 300	NA
	Heldeth Túé**	800	NA
Denmark/Greenland	Kvanefjeld	425	NA
India	Gogi	130	2024
	Lambapur-Peddagattu	130	2024
	KPM (Kylleng)	340	2028
Kazakhstan	Budenovskoe 6, 7**	2 500	2025
Mauritania	Tiris	315	NA
Mongolia	Badrakh**	1 500	NA
	Emeelt**	700	NA
	Gurvansaihan**	400	NA
Namibia[(b)]	Etango	2 770	NA
	Norasa	2 000	NA
Niger[(c)]	Dasa	1 400	2025
	Imouraren	5 000	NA
	Madaouela	950	NA
Paraguay	Yuty**	200	2035
Peru	Macusani	2 350	2035
Russia	Elkon	5 000	2040
Tanzania	Mkuju River	3 000	2030
Ukraine	Safonivske	150	2023
	Severinska	1 200	NA
United States	Reno Creek**	770	NA
	Shirley Basin**	770	NA
	Dewey-Burdock**	385	NA
	Burke Hollow**	385	NA
	Goliad**	385	NA
Zambia	Mutanga	920	NA
	Lumwana	650	NA
Total		77 138	

* As noted in country reports or from public data, in several cases, start-up dates are not known (NA). ** To be mined by ISL. (a) Australia – Uranium mining at Ranger ended in January 2021. (b) Namibia – Current mine plans foresee a cessation of Rössing production at the end of 2025. (c) Niger – Uranium mining at Cominak (Akouta) ended 31 March 2021.

Idled mines

Due to a lengthy period of low uranium prices in an oversupplied market, producers have been motivated to reduce production to reduce supply to, in turn, put upward pressure on prices. While some producers have reduced production at some facilities, others have opted to close operations entirely until market conditions improve sufficiently to justify reopening. These temporarily closed operations, referred to as idled mines (Table 1.26), are defined as those with associated identified uranium resources and processing facilities that have all the necessary licences, permits and agreements for operation and have produced commercially in the past, but were not producing uranium as of mid-2020.

Table 1.26. **Idled mines***

(as of 1 January 2021)

Country	Production centre (mine)	Year idled	Production capacity (tU/yr)	Resources (tU)
Australia	Honeymoon[(a)]	2013	770	23 300
Canada	McArthur River / Key Lake	2018	9 600	154 100
	Rabbit Lake	2016	6 500	27 000
China	Chongyi	2017	200	NA
	Lantian	2017	100	NA
Malawi	Kaylekera	2014	1 270	9 150
Namibia	Langer Heinrich	2018	2 030	36 875
	Trekkopje[(b)]	2013	2 500	36 450
United States	Willow Creek	2018	1 000	13 770
	Smith Ranch/Highland	2016	2 100	12 540
	Alta Mesa	2016	570	7 850
	Lost Creek	2020	845	7 030
	Crow Butte	2017	770	6 040
	Nichols Ranch	2020	770	3 130
	La Palangana (Hobson)	2015	385	NA
Totals			**29 410**	**337 235**

* Idled mines are those with associated identified uranium resources and processing facilities that have all necessary licences, permits and agreements for operation and have produced commercially in the past. (a) Technical difficulties contributed to decisions to stop production. (b) Although not fully satisfying the definition of an idled mine (no commercial production), it is included here because it produced 251 tU and 186 tU in 2012 and 2013 (respectively) as part of two pre-commercial pilot tests. A care and maintenance team regularly provides upkeep of the mine's infrastructure so that it can be recommissioned and brought on stream when market conditions are more favourable.

As shown in Table 1.26, annual production capacity could be increased relatively rapidly if the listed idled mines are brought back into service. Although each mine operation is unique in terms of operational costs and a threshold price for reopening, the ability to raise capital as required to resume operation and to meet regulatory requirements, idled mines could be returned to production faster, given that all permits and licences remain in place. Decisions to resume production depend principally on increased market prices. With the right market signals, idled mine facilities, associated with a total of at least 335 000 tU in local resources (recoverable), could potentially bring as much as 29 000 tU annually to the market if all are brought back into production. At least some of these facilities can reasonably be expected to be brought back online before new mines are established, should uranium market conditions improve.

Operations to recover uranium from gold tailings in South Africa could also contribute to increased global production relatively rapidly and production at Somaïr (Niger) could be returned to full capacity (capacity was reduced by 30% in 2017 due to poor market conditions) with the right market signals. Moreover, operations that have progressed to pilot mining, such as Trekkopje (Namibia), or those that have operating permits but where work to bring the site into production was suspended pending more favourable market conditions, such as Imouraren (Niger), could also increase global annual production by over 7 500 tU. Improved market conditions and significant investment, however, would be required to bring operations like these on stream (note that Trekkopje is included in the list of idled mines, while Imouraren is listed in Table 1.25 "Planned and prospective mines"; see Table 1.26 footnotes for additional details).

Sufficient uranium resources have been identified to support even the most aggressive scenarios of growth in nuclear generating capacity. However, the majority of this in-ground uranium cannot be brought to the market without improved market conditions. At the market prices of early 2021 (that is, up to the ending date that this edition covers, 1 January 2021), less than 25% of the recoverable resource base outlined in this edition could be economically brought into production, since resources with estimated mining costs greater than 80 USD/kgU (USD 30.80/lb U_3O_8) cannot be profitably mined at such prices. However, in the latter half of and continuing into 2022, uranium market prices have strengthened significantly (up to USD 64.50/lb U_3O_8 in mid-April of 2022) owing to speculation and heightened uncertainties associated with ongoing geopolitical conflict. Should such market prices be sustained, planned production cutbacks could be eased, idled mines could be brought back on stream and new mines could be developed.

It should also be noted that there is the ability to increase production more rapidly than the traditional lengthy mine development processes of the recent past. However, efforts to manage the COVID-19 pandemic at production facilities and market realignments resulting from geopolitical tensions could lead to further, unplanned reductions in production as well as restrictions to the flow of nuclear materials (including uranium) in the global marketplace, which would test the market's ability to continue providing an adequate supply of uranium to the global nuclear fuel supply chain.

Conclusions

Nearly 8 000 000 tonnes of in-ground uranium resources of economic interest (recoverable at <USD 260/kgU) have been identified in this edition. However, much of this in-ground uranium cannot be brought into production without improved market conditions. Poor market conditions have also slowed investment in uranium exploration, which could affect delineation of additional low-cost reasonably assured and inferred resources in the longer term.

At the market prices of early 2021 (the end of the reporting period for this edition of the Red Book) of about USD 30/lb U_3O_8 (USD 78/kg U), only 25% of the recoverable resource base outlined in this edition of the Red Book could be economically brought into production, since resources with estimated mining costs greater than 80 USD/kgU cannot be profitably mined at these prices. To help ensure that uranium resources are brought to market when they are needed, future supplies would benefit from timely research and innovation efforts to further improve uranium exploration and to develop new, more cost-effective extraction techniques.

However, since some producers have either idled production facilities or reduced production due to a lengthy period of low uranium prices, there is an ability to increase production more rapidly than the traditional lengthy mine development processes of the recent past. Beyond idled projects, significant investment and time could be required to bring existing uranium resources into production, particularly for high-cost, undiscovered or unconventional resources. Historically, significant proportions of identified resources have never been extracted, while, on average, the extraction of identified resources has taken one to two decades or more (see, for example, IAEA 2020, Figure 2.75), in addition to several decades for the delineation of undiscovered resources.

Looking ahead, with the easing of efforts to control the COVID-19 pandemic at production facilities, and the recent run-up in the spot price of uranium in the latter half of 2021, a modest increase in the production of uranium can be expected. However, with ongoing geopolitical tensions that threaten the continuation of some aspects of global trade in nuclear materials, the market's ability to continue supplying an adequate amount of uranium to the global nuclear fuel supply chain will be tested.

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Chapter 2. **Uranium demand and supply/demand relationship**

This chapter summarises the current status and projected growth in world nuclear electricity generating capacity and commercial *reactor-related uranium requirements* up to 2040. Relationships between uranium supply and demand are analysed and important developments related to the world uranium market are described.

Nuclear generating capacity and reactor-related uranium requirements

On 1 January 2021, a total of 442 commercial nuclear reactors were operational in the world, in 31 countries, and 52 reactors were under construction.

During 2019 and 2020, 11 reactors were connected to the grid, construction started on 8 reactors and 14 reactors were permanently shut down. Table 2.1 summarises the status of the world's nuclear power plants as of 1 January 2021. The global nuclear power plant fleet generated a total of about 2 626 TWh of electricity in 2019 and about 2 523 TWh in 2020 (see Table 2.2).

World annual uranium requirements amounted to around 60 100 tU as of 1 January 2021.

Global nuclear programmes

OECD

As of 1 January 2021, 293 reactors were operational in 19 OECD countries and constituted about 71% of the world's nuclear electricity generating capacity. During 2019 and 2020, a total of 16 reactors were under construction in OECD countries with two additional construction starts in Türkiye and the United Kingdom. In this same period, 12 reactors were permanently shut down in France, Japan, Korea, Sweden, Switzerland and the United States. A number of OECD member countries, namely the Czech Republic, France, Finland, Hungary, the Slovak Republic and the United Kingdom, remain committed to maintaining or increasing nuclear generating capacity in their energy mix. To help enable the development of small and advanced reactors, several countries have set out frameworks designed to encourage the industry to bring technically and commercially viable small reactor propositions to the global marketplace.

The OECD reactor-related uranium requirements amounted to around 40 000 tU as of 1 January 2021.

Table 2.1. **Nuclear data summary**

(as of 1 January 2021)

Country	Operational reactors in 2021	Generating capacity (GWe net)	Reactors under construction	Reactor grid connections in 2019-2020	Reactor shutdowns in 2019-2020	Reactors using MOX(b)	2020 uranium requirements (tU)*
Argentina	3	1.8	1	0	0		219
Armenia	1	0.4	0	0	0		64
Bangladesh	0	0.0	2	0	0		0
Belarus	1	1.1	1	1	0		176
Belgium	7	5.9	0	0	0		944
Brazil	2	1.9	1	0	0		400
Bulgaria	2	2.0	0	0	0		320
Canada	19	13.6	0	0	0		1 715
China(a)	50	47.5	13	4	0		8 352
Czech Republic	6	3.9	0	0	0		594
Finland	4	2.8	1	0	0		720
France	56	61.4	1	0	2	23	6 034
Germany	6	8.1	0	0	0		1 012
Hungary	4	1.9	0	0	0		348
India	22	6.8	7	0	0	1	1 350
Iran	1	0.9	1	0	0		160
Japan	33	31.7	2	0	5		3 168
Korea	24	23.1	4	1	1		3 904
Mexico	2	1.6	0	0	0		430
Netherlands	1	0.5	0	0	0	1	80
Pakistan	5	1.3	2	0	0		211
Romania	2	1.3	0	0	0		208
Russia	38	28.6	3	4	1		5 100
Slovak Republic	4	1.8	2	0	0		483
Slovenia	1	0.7	0	0	0		149
South Africa	2	1.8	0	0	0		294
Spain	7	7.1	0	0	0		946
Sweden	6	6.9	0	0	1		1 104
Switzerland	4	3.0	0	0	1		480
Türkiye	0	0.0	2	0	0		0
Ukraine	15	13.1	2	0	0		2 480
United Arab Emirates	1	1.4	3	1	0		224
United Kingdom	15	8.9	2	0	0		944
United States	94	96.6	2	0	2		16 886
Total World	442	393.2	52	11	14	25	60 114
Total OECD	293	279.5	16	1	12	24	39 941
Total Non-OECD	149	113.7	36	10	2	1	20 173

* NEA/IAEA estimate. MOX is not included in uranium requirement figures.

(a) The following data for Chinese Taipei are included in the world total but not in the total for China: four reactors in operation, 3.8 GWe net; 615 tU as 2020 uranium requirements; no reactor under construction, none started up and one shut down during 2019 and 2020.

Source: i) Government-supplied responses to a questionnaire; ii) NEA Nuclear Energy Data 2021 for OECD countries and iii) IAEA Power Reactor Information System (accessed November 2022).

Table 2.2. **Electricity generated at nuclear power plants**

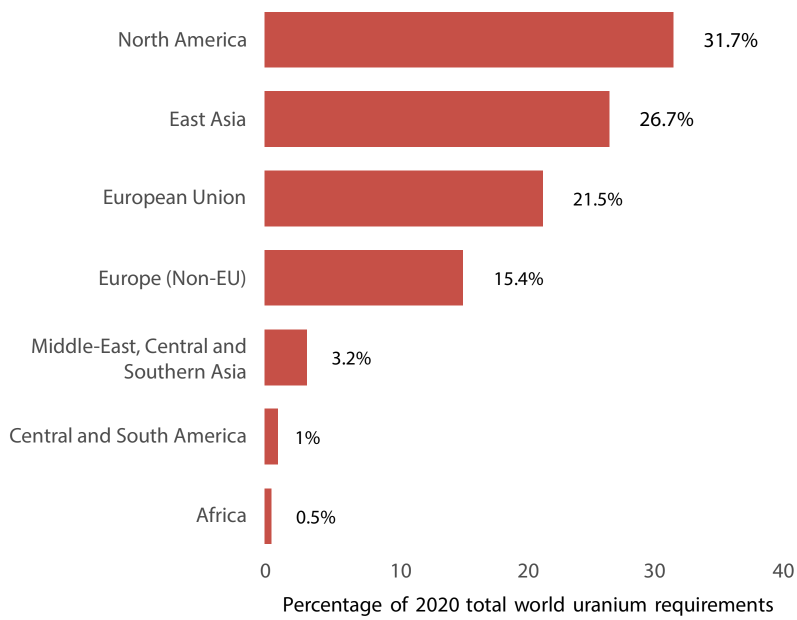
(TWh)

Country	2015	2016	2018	2019	2020
Argentina	7	8	7	8	10
Armenia	3	2	2	2	3
Belarus	0	0	0	0	0.3
Belgium	25	41	27	41	33
Brazil	14	15	15	15	13
Bulgaria	15	15	15	16	16
Canada	96	95	94	95	92
China[(a)]	161	198	277	330	345
Czech Republic	25	23	28	29	28
Finland	22	22	22	23	22
France	417	384	396	382	339
Germany	87	80	72	71	61
Hungary	15	15	15	15	15
India	35	35	35	41	40
Iran	3	6	6	6	6
Japan	9	18	49	66	43
Korea	165	154	127	139	153
Mexico	12	10	13	11	11
Netherlands	4	4	3	4	4
Pakistan	4	5	9	9	10
Romania	11	10	11	10	11
Russia	182	183	191	196	202
Slovak Republic	14	15	14	14	14
Slovenia	6	5	6	6	6
South Africa	11	15	11	14	12
Spain	55	56	53	56	56
Sweden	54	61	66	64	47
Switzerland	22	20	25	25	23
United Arab Emirates	0	0	0	0	2
Ukraine	82	76	80	78	72
United Kingdom	64	65	59	51	46
United States	797	806	808	809	790
Total World	2 452	2 473	2 563	2 657	2 556
Total OECD	1 889	1 874	1 878	1 902	1 783
Total Non-OECD	563.1	598.5	684.7	755.1	772.6

(a) The following data for Chinese Taipei are included in the world total, but not in the total for China: 35.1 TWh in 2015; 30.5 in 2016; 26.7 TWh in 2018; 31.1 in 2019 and 30.3 in 2020.

Source: i) Government-supplied responses to a questionnaire; ii) NEA Nuclear Energy Data 2021 for OECD countries and iii) IAEA Energy, Electricity and Nuclear Power Estimated for the period up to 2050 (IAEA, 2021a) for non-OECD countries.

Figure 2.1. **World uranium requirements: 60 114 tU**
(as of 1 January 2021)



European Union

In 2018, the European Commission established a Technical Experts Group on Sustainable Finance (TEG) to assist in the development of a unified classification system for sustainable economic activities (i.e. the EU Taxonomy), along with methodologies for low-carbon indices and metrics for climate-related disclosure. The EU taxonomy Regulation (EU) 2020/852 establishes uniform criteria for determining the degree of environmental sustainability of investments. On 9 March 2022 the European Commission (EC) adopted Delegated Regulation (EU) 2022/1214, which includes criteria for classifying nuclear energy as an environmentally sustainable investment and recognises that nuclear energy can contribute to the decarbonisation of the European Union's economy.

In Belgium, seven nuclear power plants provided about 40% of domestic electricity generation in 2020. Under current Belgian law, nuclear power is to be phased out by 2025. The Belgian Constitutional Court ruled in March 2020 that a law passed in 2015 to grant a ten-year extension to Doel units 1 and 2 was unconstitutional because a required Environmental Impact Assessment was never produced before granting extended operations. However, the Court said it would allow the law to remain in force until the end of 2022. The corresponding environmental impact assessment and the public consultation were performed, and a new law granting a ten-year extension to Doel units 1 and 2 was passed in 2022. In addition, the government plans to dedicate EUR 100 million over four years to investigate the potential to build new small modular reactors (SMRs).

In Bulgaria, following the closure of four older reactors by the end of 2006, only two units (about 0.95 GWe net each) remain operational at the Kozloduy Nuclear Power Plant and provided around 40% of domestic electricity production in 2020. To compensate for the loss of nuclear generating capacity and to regain its position as a regional electricity exporter without increasing carbon emissions, the government plans to build new reactors. A nuclear station at Belene was originally planned in the 1980s, but was stopped in the early 1990s due to environmental and financial concerns. In May 2019, the government advertised for a strategic investor to participate in the Belene project to build two new reactors. In January 2021, the government approved a plan for the potential building of a new nuclear power plant at the existing Kozloduy site, and announced discussions with external partners for the potential roll-out of SMRs.

In the Czech Republic, a total of six reactors were operational on 1 January 2021, with an installed capacity of 3.9 GWe net and providing around 37% of the domestic electricity production in 2020. In May 2015, the Czech government announced a national energy policy that favours an ambitious increase in nuclear power to about 50-55% by 2050 as a means to reduce carbon emissions. The Czech utility ČEZ applied to the State Office of Nuclear Safety to construct two new reactors at its Dukovany site. Under the current schedule, the reactor supplier is to be selected by the end of 2022, with commissioning expected by 2036. The Czech government would loan 70% of the cost of building a single 1 200 MWe unit, with ČEZ funding the remaining 30%. In June 2020, ČEZ stated that it expects to invest about USD 2.3 billion over the next three decades to extend the operating lifetime of the four reactors at Dukovany by a further 20 years to a total of 60 years.

In Finland, four units (two each at the Olkiluoto and Loviisa Nuclear Power Plants) with a total generating capacity of 2.8 GWe were operational on 1 January 2021, providing about 34% of domestic electricity generation in 2020. Teollisuuden Voima Oyj (TVO) owns and operates the two plant units, Olkiluoto 1 and 2, and it has deployed a third unit, Olkiluoto 3 (OL3), an Evolutionary Power Reactor (EPR) with capacity of 1.6 GWe. The OL3 construction has suffered numerous delays and cost overruns. TVO was granted an operating licence in 2019 and in April 2020 applied for permission to load fuel. OL3 was connected to the grid in March 2022. The project for the new nuclear site in Pyhäjoki to build a new VVER reactor provided by a consortium with Rosatom was cancelled in 2022. There is political support in Finland to consider new SMR builds in the future.

In France, 56 operational reactors generated 70% of domestically produced electricity in 2020. Construction of a new EPR at the Flamanville Nuclear Power Plant began in late 2007. Repairs to welds in the Flamanville 3 EPR were completed and deemed compliant by the French Nuclear Safety Authority (ASN). Fuel loading is now scheduled to start in early 2023 following start-up tests and authorisation from the ASN. In February 2020, unit 1 at Fessenheim was closed, followed by the closure of unit 2 in June 2020. The closure of the Fessenheim reactors was part of the energy policy objective to reduce the share of nuclear power to 50% by 2035. However, in late 2021, Électricité de France (EDF) proposed the construction of six EPR-2 units and the French president stated that France would pursue the construction of new reactors to maintain its energy security and to meet climate goals.

In Germany, six reactors were operational on 1 January 2021, producing about 11% of domestic electricity generation in 2020. Following the Fukushima Daiichi Nuclear Power Plant accident, the German Cabinet announced that it was accelerating the nuclear phase-out by permanently shutting down the reactors. The remaining reactors are to be permanently shut down no later than the end of 2022 in the following order: Grohnde, Gundremmingen C and Brokdorf by the end of 2021, and the three most recently built facilities – Isar 2, Emsland and Neckarwestheim – by the end of 2022. In November 2022, however, the German parliament voted that Germany’s three remaining nuclear power reactors still operating in 2022 should keep operating until mid-April 2023 to ensure the security of electricity supply. With reduced nuclear generating capacity, renewable energy sources are being added at a rapid rate, but it has also been necessary to increase the use of coal-fired plants, which in turn increases greenhouse gas emissions. In addition, coal power plants are planned to remain part of the generation mix until 2038. The Federal Ministry for Economic Affairs and Energy presented its new project funding programme in the field of safety research for nuclear facilities for the years 2021 to 2025 with a budget of approximately EUR 38 million per year. The objective of the research and development is to improve the safety of nuclear facilities and to establish and further develop the scientific basis for the safe management of radioactive waste. These objectives will continue to remain relevant after Germany’s decision to phase out the commercial use of nuclear energy.

In Hungary, four operational VVER reactors at the Paks Nuclear Power Plant (1.9 GWe net capacity) accounted for 48% of electricity generation at the end of 2020. In January 2020, the government approved the new National Energy Strategy 2030 and the National Energy and Climate Plans 2030. The preservation of nuclear generation capacity by replacing existing units at the Paks Nuclear Power Plant nearing the end of their lifetime is one of the key strategic measures for further decarbonisation of the electricity sector. Plans are well advanced for the construction of two new VVER-1200 reactors at the Paks site. Preliminary work began in June 2019 and the construction phase is expected to start in 2022-2023. The units were originally scheduled to start operating in 2025 or 2026. All of Hungary's nuclear fuel supply is contracted from TVEL in Russia. The construction licence application for the two nuclear power units is currently under review by the Hungarian Atomic Energy Authority.

With no nuclear generating capacity, Lithuania relies heavily on imports, in particular natural gas from Russia. Prospects for a new nuclear plant diminished following the election of a new coalition government in 2012, led by a party that had opposed the construction of the proposed Visaginas Nuclear Power Plant on economic grounds. In 2016, the government released its national energy strategy and announced a delay of the nuclear project until more favourable market and economic conditions arise. The Visaginas Nuclear Power Plant was planned to be built by GE-Hitachi, but has not proceeded. In April 2022, Lithuania's government stated the country was "seeking full energy independence from Russian gas".

In the Netherlands, the single operational reactor (0.5 GWe of net capacity) supplied 3% of domestically generated electricity in 2020. There are currently no plans for conventional large new nuclear build in the Netherlands. Nevertheless, it is stated in the National Climate Agreement that nuclear power is one of the options for the future energy mix. The government of the Netherlands plans to spend EUR 35 billion by 2030 to reach new climate targets, which aim at a 50% cut in emissions compared to 1990 levels, and include EUR 500 million in support for two new SMRs.

In Poland, which as of 2021 has no nuclear generating capacity, coal-fired plants generate more than 90% of domestic electricity. Poland had four 440 MWe Russian VVER-440 units under construction in the 1980s at Zarnowiec, but these were cancelled in 1990. The government continues to advance plans to construct about 6 GWe of new nuclear power generation in the next 20 years. The legal framework for the development of nuclear power was established in 2011 and the Council of Ministers instructed the Ministry of Economy to prepare a new national strategy concerning radioactive waste and spent fuel management. In 2021, the government recommitted to launching a nuclear programme with the release of a draft consultation that targets start of construction on the first of four to six reactors by 2033.

In Romania, two CANDU reactors at the Cernavoda Nuclear Power Plant provided around 20% of the electricity generated in the country in 2020. Nuclearelectrica, the state-owned utility that operates the Cernavoda Nuclear Power Plant, has also announced plans to refurbish unit 1 of the plant by 2028 in order to extend the operational lifetime for another 30 years. The project to complete Cernavoda units 3 and 4 is now also proceeding and Nuclearelectrica has estimated that unit 3 will start commercial operation in 2030, followed by unit 4 in 2031. In October 2020, an intergovernmental agreement was signed with the United States by which the United States intends to support the construction of two new Cernavoda reactors and help refurbish unit 1. In March 2019, a Memorandum of Understanding was signed with NuScale Power to evaluate the potential for SMRs in Romania. In November 2021, Romania announced the potential roll-out of SMRs in the country by 2028.

In the Slovak Republic, a total of four reactors with a combined capacity of 1.8 GWe net were operational as of 1 January 2021 and provided around 53% of the country's electricity in 2020. Construction of two additional units at the Mochovce Nuclear Power Plant has been delayed as a result of design safety improvements and technology updates and is still ongoing. Mochovce 3 completed hot testing in April 2019, and the draft permit of the Nuclear Regulatory Authority for fuel loading was released in 2020. When in operation, the new units will add 0.9 GWe of electrical generating capacity to the grid.

In Slovenia, the single nuclear reactor in operation (Krško, with 0.70 GWe capacity) is jointly owned and operated with Croatia by Nuklearna Elektrana Krško (NEK). The Krško reactor began commercial operation in 1983 and was recently granted a 20-year lifetime extension to 2043. The single unit accounted for about 38% of the electricity generated in Slovenia in 2020, although a proportion of this is exported to meet about 15-20% of Croatia's electricity requirements. An ambitious programme of safety upgrades at the Krško plant was rolled out after the Fukushima Daiichi accident, and was completed in 2021. The government of Slovenia will make a decision by 2027 on whether to build a second unit at the Krško Nuclear Power Plant site.

In Spain, seven operational nuclear reactors with a total generating capacity of 7.1 GWe provided 22% of total domestically generated electricity in 2020. The government approved in March 2021 the national energy and climate plan, which includes the phasing out of nuclear energy by 2035. In May 2020, the Spanish Nuclear Safety Council granted permission for Almaraz 1 and 2 to operate until 2027 and 2028, respectively. In addition, Vandellós 2 applied for a licence extension to 2030. In May 2020, the State Company for Radioactive Waste and Decommissioning, Enresa, applied for the phase 1 dismantling authorisation of the Santa Maria de Garoña Nuclear Power Plant.

In Sweden, six operational reactors (with 6.6 GWe net capacity) generated about 30% of domestic electricity supply in 2020. At the end of 2019, Ringhals 2 was shut down after 44 years of operation and the Ringhals 1 reactor finally ceased operations on 31 December 2020. In June 2019, the Swedish Radiation Safety Authority approved Forsmark 1 and 2 to operate for a further ten years, until 2028. For the remaining reactors, plans remain to continue operation for up to 60 years.

North America

In Canada, 19 operating reactors provided about 15% of the county's electricity needs in 2020 and should continue to play an important role in the future. The province of Ontario has 18 of those operating nuclear power reactors across three power plants: Pickering, Darlington and Bruce. A CAD 26 billion refurbishment plan for Ontario's nuclear reactors will see the sequential refurbishment of four units at the Darlington site and six units at the Bruce site. The refurbishment of the Darlington Nuclear Generating Station began with work on the first reactor in 2016 and is expected to be completed by 2026. The Bruce project started with unit 6 in early 2020 and will be completed by 2033. Ontario's third operating nuclear power plant, Pickering, was originally scheduled to shut down in 2020, but the Canadian Nuclear Safety Commission (CNSC) extended the plant's licence to at least 2026. The federal government and other partners have advanced efforts in priority areas, such as developing SMR research and development and exploring business partnerships for potential deployment in the late 2020s. The CNSC continues to work to ensure readiness so as to regulate SMRs in Canada. As of June 2021, 12 SMR technology companies applied to the CNSC for the Pre-Licensing Vendor Design Review process.

In Mexico, the two units at the Laguna Verde Nuclear Power Plant (a total of 1.6 GWe net capacity) provided about 5% of the electricity generated in the country in 2020. Laguna Verde units received permission from the national regulator to operate at the extended power uprate level (120%). In July 2020 Mexico's nuclear regulator approved a 30-year extension to the operating licence of Laguna Verde 1, allowing it to operate until July 2050, and a similar application for a lifetime extension was submitted for unit 2 in 2020.

In the United States, 94 reactors were operational as of 1 January 2021, contributing 19.7% of the total electricity generated in the country in 2020. Two AP1000 reactors are currently under construction at the Vogtle power plant in the state of Georgia. In April 2020, Indian Point 2 was shut down four years before the expiry of its operating licence, and Duane Arnold-1 (601 MWe) was shut down in October 2020. A total of 6.8 GWe of nuclear capacity in eight states has thus closed before the end of the licensed operating period between 2013 and 2021. However, states and utilities are acting in support of nuclear power. For example, the New Jersey Board of Public Utilities voted in 2021 to extend zero emissions credits for nuclear power plants and the Illinois state legislature passed a law that includes about USD 700 million in subsidies over five years to keep the Byron, Dresden and Braidwood nuclear power plants in operation. The US Nuclear Regulatory Commission first approved and then reversed a 20-year licence extension for Turkey

Point 3 and 4, authorising the reactors to operate for a total of up to 80 years. On the industry side, TerraPower recently announced plans to build its Natrium reactor at a retiring coal plant in Wyoming, which currently receives almost 90% of its electricity generation from fossil fuels. The US Department of Energy is investing nearly USD 2 billion to support the licensing, construction and demonstration of this first-of-a-kind reactor by 2028. In July 2020, the US International Development Finance Corporation lifted its legacy prohibition on funding nuclear energy projects overseas.

East Asia

Prospects for nuclear growth are greater in East Asia than in any other region of the world, principally driven by rapid growth of nuclear capacity in China. Recent changes in the official energy strategy of Japan and Korea have put national reliance on domestic nuclear energy back in the main scene.

In China, 50 operational reactors with a total installed capacity of around 47.5 GWe provided about 5% of national electricity production in 2020. Recent developments include the grid connection in June 2019 of Taishan 2, the second EPR to start operation. In November 2019, China's first commercial nuclear heating project began operating at the Haiyang Nuclear Power Plant with two AP1000 units. In 2020, hot testing was completed at the Fuqing 5, one of the first Hualong One domestic design reactors under construction in China. A total of 13 reactors were under construction as of 1 January 2021. In the period 2019 to 2021, 7 new reactors totalling capacity of 7.6 GWe were connected to the grid. Projected nuclear growth remains strong in China and the country is moving ahead with the planning and construction of new nuclear power plants and the development of its own Gen III technologies. The government plans to add significant nuclear generating capacity in order to meet rising energy demand and limit greenhouse gases and other atmospheric emissions since poor air quality, mainly due to emissions from coal-fired plants, is a significant health issue. As China aims to increase its installed nuclear capacity, it is also aiming at becoming self-sufficient in the nuclear fuel supply and fuel cycle aspects and has initiated a number of domestic projects, often in co-operation with foreign suppliers, to meet these goals.

In Japan, nuclear energy in 2020 provided only around 5% of domestic electricity generation (from over 30% before 2011). With most of Japan's 33 nuclear power plants out of service, Japanese utilities have been importing large amounts of oil and natural gas for electricity generation, driving electricity prices and greenhouse emissions upward. Reactor restarts and rejuvenation of the industry is, however, proving to be challenging given the stringent new regulatory requirements and public resistance. Nevertheless, the finalisation in 2015 of a new long-term energy policy that envisions nuclear power representing 20-22% of total energy supply in 2030 represented an important step for a sustained nuclear comeback. Sendai 1 and 2 were the first reactors to restart in 2015, and a further eight have restarted since then. Mihama 3 reactor, which had been idle since 2011, was restarted in June 2021. However, in October 2021 the utility took the reactor offline to implement antiterrorism measures, a requirement of new regulations introduced by the Nuclear Regulation Authority. Mihama 3 had been granted a licence extension in 2016 to operate beyond 40 years. As of 2022, 16 reactors were in the process of restart approval. Reactors that have restarted are also required to construct bunkered backup control centres within five years of regulatory approval to restart.

In Korea, 24 operational reactors produced around 30% of the total electricity generated in 2020. Construction of four reactors (5.4 GWe additional capacity) is underway. Shin-Hanul unit 1 was connected to the grid in mid-2022. On the other side, Kori units 2 and 3 will be permanently shut down by the end of 2024. An energy transition policy was announced in October 2017, outlining a long-term phasing out of nuclear power. However, the newly elected government in 2022 has since changed this policy and set instead a target for nuclear energy to provide a minimum of 30% of electricity in 2030 and 35% by 2036.

Although Mongolia does not currently have nuclear generating capacity, it has signalled an interest in the use of small and medium-sized reactors.

Europe (non-EU)

This region is undergoing strong growth with reactors under construction. Several countries in this region continue to support nuclear power and overall growth in nuclear generating capacity is expected.

In Armenia, the single operational reactor (Metsamor 2, with 0.4 GWe capacity) provided about 34% of the electricity generated in the country in 2020. In 2015, the nuclear power plant began a large-scale life extension maintenance programme with the help of Rosatom. In October 2021 ANRA, the regulator, extended the operating licence to 2026. According to the Armenian energy sector development plan, construction of one new unit is envisaged by 2027.

In Belarus, a USD 10 billion agreement financed by Russia was signed with Rosatom's Atomstroyexport in 2012 to build the country's first nuclear power plant. It consists of two VVER-1200 reactors, with unit 1 connected to the grid in November 2020 and unit 2 still under construction as of 2022.

In Russia, 38 operational reactors (with 28.6 GWe net capacity) provided about 21% of the total electricity generated in the country in 2020. Russia has brought 10 reactors online in the period 2011-2021, including the two Akademik Lomonosov floating nuclear power plants. Rosatom has confirmed its intention to commission two other floating nuclear power plants by 2027. In April 2020, the Russian nuclear regulator extended the operating licence of the Beloyarsk BN-600 fast reactor by five years to 2025. As of 1 January 2021, three reactors were under construction in Russia. In 2021, Rosatom was granted a construction licence for the BREST-OD-300 reactor, a lead-cooled fast reactor. The reactor is due to start operating in 2026 and is part of a pilot demonstration programme aimed at closing the nuclear fuel cycle. The programme also includes the design and construction of reference SMR power units. In addition to an active domestic programme, the state-run energy company Rosatom is currently involved in new reactor projects in several countries (e.g. Bangladesh, Belarus, China, Hungary, India, Iran, Türkiye and Uzbekistan).

In Switzerland, four operating reactors produced 33% of the electricity generated in the country in 2020. Switzerland's first nuclear power plant, Mühleberg, with an approximate output power of 373 MW, was permanently shut down on 20 December 2019. In 2017, a public referendum was organised on the new Energy Strategy 2050. Under the new law, no permits for the construction of new nuclear power plants or any basic changes to existing nuclear power plants will be delivered. The existing nuclear power plants may remain in operation for as long as they are declared safe by the Federal Nuclear Safety Inspectorate.

In Türkiye, the government continues to advance its nuclear development programme as its economy faces rapidly escalating electricity demand. Construction of the country's first nuclear power reactor, the first of four VVER-1200 units at Akkuyu, started in April 2018. A construction licence for unit 2 was issued in September 2019. Construction of the second and third reactor units at the Akkuyu began in 2020 and 2021, respectively. In 2021, preparations began for the construction of the fourth unit. In March 2021, Akkuyu Nuclear, a subsidiary of Russia's Rosatom, received two loans from Sovcombank to finance the construction of the Akkuyu Nuclear Power Plant. The first unit is expected to be in operation by 2023.

In Ukraine, 15 reactors with a combined net installed capacity of 13.1 GWe were operational on 1 January 2021, producing 51% of the electricity generated in the country in 2020. The national energy programme foresees that nuclear energy will continue to generate about 50% of total electricity production by 2035. In February 2022, Russia launched a military offensive against Ukraine. In early March 2022 the Zaporizhzhia plant in south-eastern Ukraine became the first operating civil nuclear power plant to come under armed attack. Ukraine had been receiving most of its nuclear services and nuclear fuel from Russia. In June 2022 an agreement was signed with Westinghouse that will see the company provide all fuel for the Ukrainian reactors.

In the United Kingdom, 15 operational reactors with a combined capacity of 8.9 GWe net as of 1 January 2021 provided 14.5% of total domestic electricity generation in 2020. In the coming decades, the current UK fleet will be shut down, with the first units expected to come offline in

2023 and the last currently expected to close by 2035. The government has taken a series of actions to encourage nuclear new build. EDF, China General Nuclear Power Group (CGN) and the development vehicle NNB Generation Company HPC Limited are constructing two EPRs at Hinkley Point C (3.2 GWe). In January 2021, the United Kingdom also entered negotiations with EDF in relation to the Sizewell C project in Suffolk. In December 2020, the United Kingdom published the response to the consultation on a regulated asset base (RAB) model for private investment in new nuclear generation. Having assessed the consultation responses, the UK government believes that a RAB model remains credible for large-scale nuclear projects. The UK government is thus continuing to explore a RAB model with developers. On the other side, the United Kingdom's advanced gas-cooled reactor (AGR) nuclear power stations have been scheduled to progressively reach the end of their operational timespans by 2030. The two-unit Dungeness B was shut down in June 2021, while Hunterson B-1 in Scotland ceased operations in November 2021. The government is investing more than GBP 100 million of innovation and industrial strategy funding into advanced nuclear research and development to help the development of SMRs and advanced modular reactors (AMRs) in the United Kingdom.

Middle East, Central and Southern Asia

Nuclear generating capacity in this region is expected to grow in coming years as governments continue to implement plans to meet rising electricity demand without increasing greenhouse gas emissions.

In Bangladesh, a deal with Rosatom was ratified in 2012 to build two reactors at the Rooppur site. Under the terms of the agreement, Russia will reportedly provide support for construction and infrastructure development, supply fuel for the entire lifetime of the reactors and take back spent fuel. The first safety-related concrete for unit 1 was poured in 2017, with the pour for unit 2 in 2018. The Bangladesh Atomic Energy Commission planned to commission the two VVER-1200 in 2023 and 2024, respectively. However, it is still not clear to what extent COVID-19 may have slowed the work.

In India, 22 reactors (with 6.2 GWe net capacity) were operational on 1 January 2021, providing about 3.3% of domestic electricity generation in 2020. Agreements in 2008 that granted India the ability to import uranium and nuclear technology have resulted in improved reactor performance. However, concerns about nuclear liability legislation have slowed the development of agreements on imported technology. In 2021, construction of seven new reactors was in progress, with four indigenous pressurised heavy water reactors (PHWRs), two VVERs and one sodium fast reactor. As other countries with PHWR fleets have done, India has started the process of refurbishing its reactors to allow for extended operation. The national plan is to increase installed nuclear capacity to 15.7 GWe by 2031, following the 2019 announcement of India's Department of Atomic Energy. In 2021, Kakrapar-3 was connected to the grid.

In the Islamic Republic of Iran, one operational 900 MW reactor (Bushehr-1) supplied by Atomstroyexport provided 1.7% of domestic electricity production in 2020. Another reactor, Bushehr-2, also of Russian design, has been under construction since 2017. The second reactor is expected to start up in 2024. The government plans to develop up to 8 GWe of net installed nuclear capacity by 2030 in order to reduce its reliance on fossil fuels. The country also has a major programme of uranium enrichment.

In Pakistan, five reactors (with 1.3 GWe net capacity) were operational on 1 January 2021, supplying about 7% of domestic electricity production in 2020. On 1 January 2021 two reactors were under construction in Pakistan but they have since been connected to the grid, in 2021 and 2022, respectively. As part of an effort to address chronic power shortages, a growing population and increasing electricity demand, the government established the Energy Security Action Plan with a target of installing additional nuclear generating capacity by 2030. The Pakistan Atomic Energy Commission signed a contract with China (CNNC) in 2017 for a Hualong One reactor, the country's third of the kind after two units were installed at Karachi. China's Import and Export Bank is expected to provide the major part of the financing for the unit, Chashma-5.

In the United Arab Emirates, one unit of 1.3 GWe provided around 1% of the domestic electricity production in 2020. In late 2009, ENEC (the Emirates Nuclear Energy Corporation) announced that it had selected a bid from a Korean KEPCO-led consortium to build four APR1400 reactors, to be built at the Barakah site. As of 1 January 2021, three pressurised water reactors (PWRs) were under construction at the Barakah Nuclear Power Plant and two of them (Barakah-2 and Barakah-3) have since connected to the grid, in 2021 and 2022 respectively. The last unit, Barakah-4 started construction in 2015 and in 2022 was in the final stages of commissioning prior to construction completion.

Other countries in the region, currently without nuclear power plants, have been considering the development of such facilities.

Jordan currently has no nuclear generating capacity. A plan to construct two reactors to generate electricity and desalinate water, and to develop the country's uranium resources, had been moving forward, driven by rising energy demand and the need to reduce energy imports, which meet around 95% of national needs. However, the project to build these two VVER reactors has since been cancelled and the country is now considering SMRs instead. It signed in 2018 several co-operation agreements with CNNC, Rolls-Royce, NuScale, X-energy and Rosatom.

Kazakhstan continued to be the world's largest uranium producer in 2021, but the country has no active nuclear power generation capacity. In May 2014, Russia and Kazakhstan signed a preliminary co-operation agreement regarding the construction of a new nuclear power plant with generating capacity of between 300 and 1 200 MWe. Discussions on building a nuclear power plant in Kazakhstan are still pending.

Saudi Arabia is seeking to build its first nuclear power plant and has solicited information from various vendors from China, France, Korea, Russia and the United States. In January 2021, the energy minister said that the country is committed to becoming carbon neutral and that it aimed to produce 50% of its electricity from renewables by 2030, with the remaining 50% supplied by natural gas.

In Uzbekistan, the world's fifth uranium producer as of 2021, the Uzbek Agency for the Development of Nuclear Energy (UzAtom) and Russia's Rosatom are working on finalising an Engineering, Procurement, Construction (EPC) contract for Uzbekistan's first two commercial reactors. In 2020, a 10-year plan for Uzbekistan's electricity sector was developed with the Asian Development Bank and the World Bank. It aims to develop up to 30 GW of additional power capacity by 2030, including 5 GW of solar power, 3.8 GW of hydro energy, 2.4 GW of nuclear energy, and up to 3 GW of wind power. In May 2020 the country's Ministry of Energy published a report on its strategy for electricity generation through 2030, which forecasts 15% of the country's electricity coming from nuclear energy by 2030, with 8% from solar and 7% from wind.

Central and South America

Governments in Argentina and Brazil continue to support nuclear power, suggesting some growth in nuclear generating capacity in the long term, despite other countries in the region reportedly turning away from nuclear following the Fukushima Daiichi accident.

In Argentina, three reactors were operational on 1 January 2021, accounting for 7% of domestic electricity production in 2020. The Embalse reactor returned to service in 2020 following a three-year upgrade and refurbishment programme that will allow it to operate for a further 30 years. In addition to providing electricity, Embalse can now also produce Cobalt-60 for medical and industrial applications. In April 2020 a 20-year lifetime extension project for Atucha 1, which currently has a licence to operate until 2024, was resumed. Work continues on the Carem-25 small modular reactor (SMR) at the site adjacent to the Atucha Nuclear Power Plant. In July 2021, a contract was signed between Nucleoelectrica (NA-SA) Argentina and the country's National Atomic Energy Commission to complete construction of the Carem-25 within three years. There are plans to build other larger units by 2032, potentially of Chinese design. In August 2021 NA-SA was reported to be considering a Canadian project for a CANDU reactor at a still-undecided site.

In Brazil, two reactors (Angra 1 and 2, with 0.5 GWe and 1.3 GWe net capacity, respectively) were operational on 1 January 2021, providing about 2% of electricity generated in the country in 2020. Construction of the Angra-3 reactor (1.2 GWe net) was restarted in 2010 but was then suspended in 2015 following cost overruns and corruption issues. Recently, Brazil approved a plan to complete Angra 3 in Brazil's Investment Partnership Program. The plan allows for Electronuclear to recruit a partner to help finance the project and share its ownership (minority stake) and operation. The national long-term electricity supply plan includes installing 4 GWe of nuclear generating capacity by 2030 to help meet rising energy demand.

Other countries in the region, including Bolivia, Chile, Cuba, Uruguay and Venezuela, do not have nuclear power plants but have been considering developing them. Venezuela has put its nuclear development plans on hold.

Africa

Nuclear capacity remained constant in Africa, with the region's only two operational reactors located in South Africa. However, government plans to increase nuclear generating capacity are projected to drive growth in this region. Although several countries are considering adding nuclear power plants to the generation mix to help meet rising electricity demand, development of the required infrastructure and human resources could delay these ambitions.

In South Africa, two operational units (for a total of 1.86 GWe net capacity) accounted for about 6% of the total electricity generated in the country in 2020. Early in 2020, South Africa's government issued a nuclear energy roadmap calling for the development of 2.5 GWe of new nuclear capacity, including small modular reactors to bolster employment, enhance energy security and reduce carbon emissions. In June 2020, the government revived prospective nuclear new build plans by issuing a Request for Information to vendors of both large conventional reactors and SMRs for information on their technologies and possible financing strategies.

In Egypt, as of January 1 2021 preparation work was underway to host four VVER-1200 units at the country's first nuclear power plant at the El Dabaa site. In February 2021, representatives from the Russian and Egyptian governments reported that the COVID-19 pandemic had slowed preparations at the site, and by May 2021 the expectation was that a construction permit for unit 1 would be issued in July 2022. The Nuclear Power Plants Authority applied to ENRRA for construction permits for units 1 and 2 in June 2021. In 2022 construction of the first two units started. Egypt's energy minister and Russia's Rosatom had previously signed several contracts, including a "turnkey" contract, the supply of nuclear fuel for the plant's 60-year lifetime, operation and maintenance for the first 10 years, and a contract for the training of Egyptian personnel. Previously, the Egyptian president had issued a decree approving a USD 25 billion loan from Russia to Egypt covering 85% of the project costs.

Although no other countries in Africa have nuclear power plants at this time, several have expressed interest in recent years in developing nuclear power for electricity generation and desalination, including Algeria, Ghana, Kenya, Morocco, Namibia, Niger, Nigeria, Tanzania, Tunisia and Uganda.

South-eastern Asia

No reactors were operational in this region at the end of 2021 but several countries are considering nuclear development plans, as the region continues to experience strong economic growth. Concerns about climate change, security of energy supply and energy mix diversification along with volatile fossil fuel prices are driving nuclear development policies, but political support has generally been weak owing to public safety and cost concerns.

Malaysia adopted a target of 2 GWe of nuclear generating capacity in 2011, driven by an emerging gap in electricity production and the need to diversify the energy mix. However, it was reported that the programme was postponed as a result of public distrust following the Fukushima Daiichi Nuclear Power Plant accident. Work continues through efforts to promote public acceptance, adopt the necessary regulations, sign required international treaties and obtain low-cost financing.

In Thailand, a revision of the National Energy Policy Council scaled back the planned contribution of nuclear energy to electricity generation from 10% to 5% and set back the schedule for the installation of the first unit from 2020 to 2028. The postponements were implemented to ensure safety and improve public understanding of nuclear energy. Currently, Thailand relies on natural gas to generate over 70% of its electricity.

In Viet Nam, the government had a goal in the years 2000 for nuclear power to supply as much as 25% of domestic electricity production by 2050, as a result of increasing electricity demand. In 2015, Rosatom and Electricity of Vietnam signed a framework agreement for the construction of unit 1 at the proposed Ninh Thuan Nuclear Power Plant. However shortly after, in November 2016, the Vietnamese Parliament voted to abandon its nuclear programme in favour of gas and coal.

The governments of Indonesia, the Philippines and Singapore have considered the use of nuclear power to help meet rising electricity demand despite recurring large-scale natural hazards. In July 2020, the president of the Philippines issued an executive order to set up an interagency panel to look at creating a national policy for nuclear energy. Coal-fired power generation accounts for more than half of electricity generation in the Philippines.

Pacific

This region has no commercial nuclear capacity at present. Current policy prohibits the development of commercial nuclear energy in Australia. However, a new interest in nuclear power was prompted by the South Australian premier in 2015 when it was announced that a Royal Commission would investigate South Australia's future role in the nuclear fuel cycle. In 2019, Australia's House of Representatives Standing Committee on the Environment and Energy commenced an inquiry into the prerequisites for nuclear energy production in Australia. The committee considered a range of matters, including energy affordability and reliability, economic feasibility and workforce capability, waste management, health and safety, environmental impacts, community engagement and national consensus.

Projected nuclear power capacity and related uranium requirements to 2040

Factors affecting nuclear capacity and uranium requirements

Reactor-related requirements for uranium over the short term are fundamentally determined by installed nuclear capacity. Since near-term capacity is made up of reactors that are either already in operation or under construction, short-term requirements can be projected with greater certainty. However, even with a fixed installed nuclear capacity, uranium requirements also depend on other factors linked to the performance and operation of installed nuclear power plants and fuel cycle facilities. These factors include fuel cycle length, enrichment level, discharge burn-up, as well as strategies employed to optimise enrichment services according to the price of natural uranium (NatU), as reflected in the level of tails assays chosen in the enrichment phase (see Table 2.3). For example, a reduction of the enrichment tails assays from 0.3 to 0.25% ^{235}U would, all other factors being equal, reduce uranium demand by about 9.5% and increase enrichment demand by about 11% (the tails assays selected by the enrichment provider is dependent on many factors, including the ratio between natural uranium and enrichment prices). Generally, increased uranium prices have provided an incentive for utilities to reduce uranium requirements by specifying lower tails assays at enrichment facilities, to the extent possible.

Energy availability and capacity (or load) factors also play an important role in determining uranium requirements. Load factors have increased to over 80% in the period 2000-2010 (IAEA, 2020). Increased load factors tend to increase uranium requirements. The world average load factor declined to 77.4% in 2011 and further to 73.1% in the period 2012-2015 (IAEA, 2020b) following the Fukushima Daiichi Nuclear Power Plant accident. In the period 2019-2021, the average energy availability factor calculated for 446 reactors in the world increased instead again to 79.5% (IAEA, 2020b).

Table 2.3. **Uranium demand sensitivity to some parameters**

Factor	Base value	Change	Impact on uranium requirements
Capacity (or load factor)	80%	+5% -5%	+6% -6%
Tails assays	0.25%	+0.03% -0.03%	+6% -6%
Burn-up	40 GWd/tU	+5 GWd/tU +10 GWd/tU	-3% -4-5%
Cycle length	12 months	+6 months +12 months	+7% +18%

Source: WNA, 2019; NEA/IAEA estimate.

After the Fukushima Daiichi Nuclear Power Plant accident, overcapacity in the enrichment market incentivised operators to "underfeed" enrichment facilities by extracting more ^{235}U from the uranium feedstock. This reduces the amount of uranium required to produce contracted quantities of enriched uranium and, in turn, creates a stockpile of uranium. In recognition of these recent market trends, and since the 2012 edition of the Red Book, uranium requirements for the operational lifetime of projected new reactors in this publication have been reduced from 175 tU/GWe/yr, the original assumption being a tails assay of 0.30%, to 160 tU/GWe/yr, under the new assumption of a tails assay of 0.25% over the lifetime of the reactor. In the absence of data provided by governments, this is the uranium requirement factor which has been applied in this edition of the Red Book.

Enrichment providers have indicated that they are considering re-enrichment of depleted uranium tails in modern centrifuge facilities as an economic means of creating additional fissile material suitable for use in civil nuclear reactors.

World uranium requirements, which are defined in the Red Book as anticipated acquisitions, not necessarily consumption, are expected to increase in the coming years as a significant amount of capacity currently under construction comes online, particularly in Asia. Installation of new nuclear capacity will increase uranium requirements, not only because of the additional capacity that will have to be fuelled but also because first load fuel requirements are around 60% higher than reloads for plants in operation. The strong performance and economic competitiveness of existing plants, chiefly because of low operating, maintenance and fuel costs, has made retention and improvement of existing plants desirable in many countries. This has resulted in a trend to keep existing plants operating as long as this can be achieved safely and upgrading existing generating capacity where possible (i.e. long-term operation).

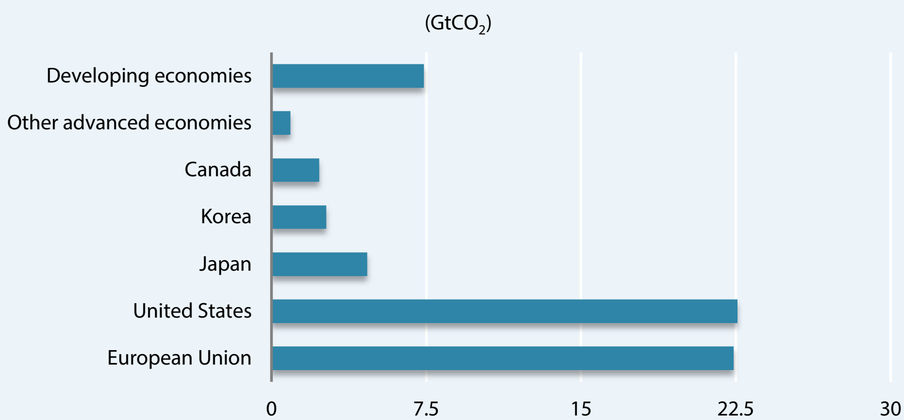
Significant nuclear build programmes are underway in China and continue in India. Although the impacts of the global financial crisis have slowed the implementation of ambitious new build plans in some countries, several other nations remain committed to long-term growth in nuclear generating capacity. Smaller scale programmes to increase nuclear generating capacity are underway in the Czech Republic and Finland, for example, while Poland continues to work towards the construction of its first reactors.

Box 2.1. Nuclear power and clean energy transitions

Nuclear power has avoided about 63 Gt of CO_2 emissions over the past 50 years, a quantity equivalent to 2 years of global energy-related CO_2 emissions (IEA, 2019). Without nuclear power, emissions from electricity generation would have been almost 20% higher. About 90% of the avoided emissions were in advanced economies, with the European Union and United States each avoiding approximately 22 $GtCO_2$ (see Figure 2.2). Without nuclear power, emissions from electricity generation would have been 25% higher in Japan, 45% higher in Korea and over 50% higher in Canada over the period 1971-2018 (IEA, 2019).

In order to be on track with sustainability targets, including international climate goals, the expansion of clean electricity would need to be three times faster than at present (IEA, 2019). It would require 85% of global electricity to come from clean sources, by 2040, including nuclear, compared with just 36% today. In the absence of further lifetime extensions and new nuclear projects, it could result in additional 4 billion tonnes of CO_2 emissions, underlining the importance of the nuclear fleet to low-carbon energy transitions around the globe.

Figure 2.2. **Cumulative CO_2 emissions avoided by nuclear power in selected countries over the period 1971-2018**



Source: IEA, 2019

The extent to which nuclear energy is seen as instrumental in meeting low-carbon reduction targets will have a clear effect on the role that nuclear energy is able to play in meeting future electricity demand, and therefore, a clear impact in uranium requirements worldwide. As noted in (NEA, 2022), while the potential exists for nuclear energy to play a much larger role in global climate change mitigation efforts, various enabling conditions would be required. To seize the window of opportunity, the nuclear sector must move quickly to demonstrate and deploy both near-term and medium-term innovations, including Generation IV and small modular reactors.

Projections to 2040

Projections of nuclear capacity and reactor-related uranium requirements are based on official responses from member countries to questionnaires circulated by the NEA/IAEA and projections established by an expert group (IAEA/NEA) and published in the IAEA report *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050*. Because of the uncertainty in nuclear programmes from 2020 onwards, high and low values are provided. The low case forecast assumes current market and technology trends continue with few additional changes in policies and regulations affecting nuclear power and includes implementation of phase-out or reduced nuclear generation policies. The high case assumes that current rates of economic and electricity demand growth continue. It also assumes changes in country policies towards the mitigation of climate change.

Forecasts of installed capacity and uranium requirements, although uncertain because of the factors mentioned in the previous section, continue to point to long-term growth. World installed nuclear capacity (see Table 2.4) in the low case scenario is projected to remain flat through 2040 (from around 390 GWe at the beginning of 2021 to about 394 GWe by the year 2040) or to significantly increase in the high case scenario, to 677 GWe. By 2030, the high case scenario projection sees an increase of 23% with respect to the 2021 level, indicating that significant expansion activities are already underway in several countries, compensating the announced nuclear power plant closure programmes in others.

Table 2.4. **Installed nuclear generating capacity to 2040***

(GWe net)*

Region	2020	2021	2025 low	2025 high	2030 low	2030 high	2035 low	2035 high	2040 low	2040 high
European Union	104.3	100.4	96.5	97.4	89.8	96.6	85.6	104.6	78.7	121.0
North America	111.8	110.7	97.2	111.7	87.3	111.8	72.4	112.8	64.6	115.4
East Asia	106.1	107.7	108.8	125.5	123.9	169.1	126.1	207.8	141	258.1
Europe (non-EU)	55.1	52.6	45.8	49.4	49.4	58.6	51.7	70.2	56.3	93.0
Central and South America	3.7	3.5	3.5	3.6	4.9	4.9	4.5	6.6	7.0	10.7
Middle East, Central and South Asia	10.4	12.7	17.6	20.0	23.8	35.8	33.8	52.8	37.7	61.8
South Eastern Asia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5.0
Africa	1.8	1.9	1.9	1.9	1.9	1.9	4.3	8.7	7.7	11.7
Pacific	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
World Total	393.0	390.0	371.0	410.0	381.0	479.0	378.0	564.0	394.0	677.0

* NEA/IAEA estimate based on government-supplied responses to a questionnaire and data established by a group of experts (IAEA/NEA) and published in IAEA, 2021a, 2022.

These projections are subject to uncertainty[1], since the role that nuclear power will play in the future generation mix in some countries has not yet been determined. Over the short term, in both the low and high case, competitive challenges from other electricity generation sources, along with nuclear policy hurdles, will continue to affect nuclear growth in some regions of the world. In addition, new safety requirements have in general strengthened the robustness of responses to extreme events, but the costs of implementing these measures could reduce the competitiveness of nuclear power in some liberalised markets.

Several currently operating reactors, mainly in OECD countries, were set on a path for early decommissioning as a result of economic challenges or policy decisions. Nevertheless, in 2018, construction started on the first of four planned reactors in Türkiye and the first formal start of nuclear construction in the Western Europe since 2007 began at Hinkley Point C, in the United Kingdom. The high case projection for Japan sees installed capacity staying about the same, as several reactors remain in service and ageing units are replaced by new reactors.

1 For instance, estimations to 2050 by IEA (2021b) which are considered conservative, project a nuclear generating capacities of around 810 GWe in 2050. These do not include, like the estimations presented in this work, the potential role that nuclear innovation may play in the future (SMRs or other emerging electric and non-electric applications of nuclear) (NEA, 2022).

Nuclear capacity projections vary considerably from region to region. The East Asia region is projected to experience the largest increase and could result in the installation of between 33 GWe and 150 GWe of new capacity in the low and high cases, respectively, by the year 2040, representing an increase between about 30% and 155% compared with 2020 capacity

Other regions projected to experience significant nuclear capacity growth include the Middle East, and the Central and Southern Asia region, notably with India's ambitious expansion plan and several potential newcomer countries (Kazakhstan, Saudi Arabia or Uzbekistan). In the high case scenario, nuclear capacity in non-EU member countries on the European continent is projected to increase considerably, with 75 GWe of capacity projected by 2040 in the high case (increases of about 66% over 2020 capacity). More modest growth is projected in Africa, Central and South America and the South-eastern Asia regions.

For North America, the projections see nuclear generating capacity decreasing by 2040 in both the low and high case, depending largely on future electricity demand, lifetime extension of existing reactors and government policies with respect to greenhouse gas emissions. The reality of financial losses at several reactors in the United States has resulted in a larger number of premature shutdowns to be assumed. In Canada, despite the reactor refurbishment programme that will result in the long-term operation of the existing fleet, there is little support for new reactor construction in the period to 2040, with the exception of small modular reactors. In the EU, nuclear capacity in 2040 is projected to decrease by around 20% in the low case scenario but increase by around 30% in the high case. The low case projection includes the implementation of phase-out or reduced nuclear generation policies, continued growth of intermittent renewable energy sources and weak growth in electricity demand. In the high case, phase-out policies are maintained, but plans for the installation of additional nuclear generation capacity are assumed to be successfully realised in the Czech Republic, Finland, Hungary, Romania, Poland and the United Kingdom.

As in the case of nuclear capacity, uranium requirements vary considerably from region to region, reflecting projected capacity increases and possible inventory building. Annual uranium requirements are projected to be largest in the East Asia region, where increased installed nuclear generating capacity (particularly in China) drives significant growth in uranium needs. World reactor-related uranium requirements by the year 2040 are projected to increase to a total of between 63 040 tU/yr in the low case and 108 272 tU/yr in the high case (see Table 2.5).

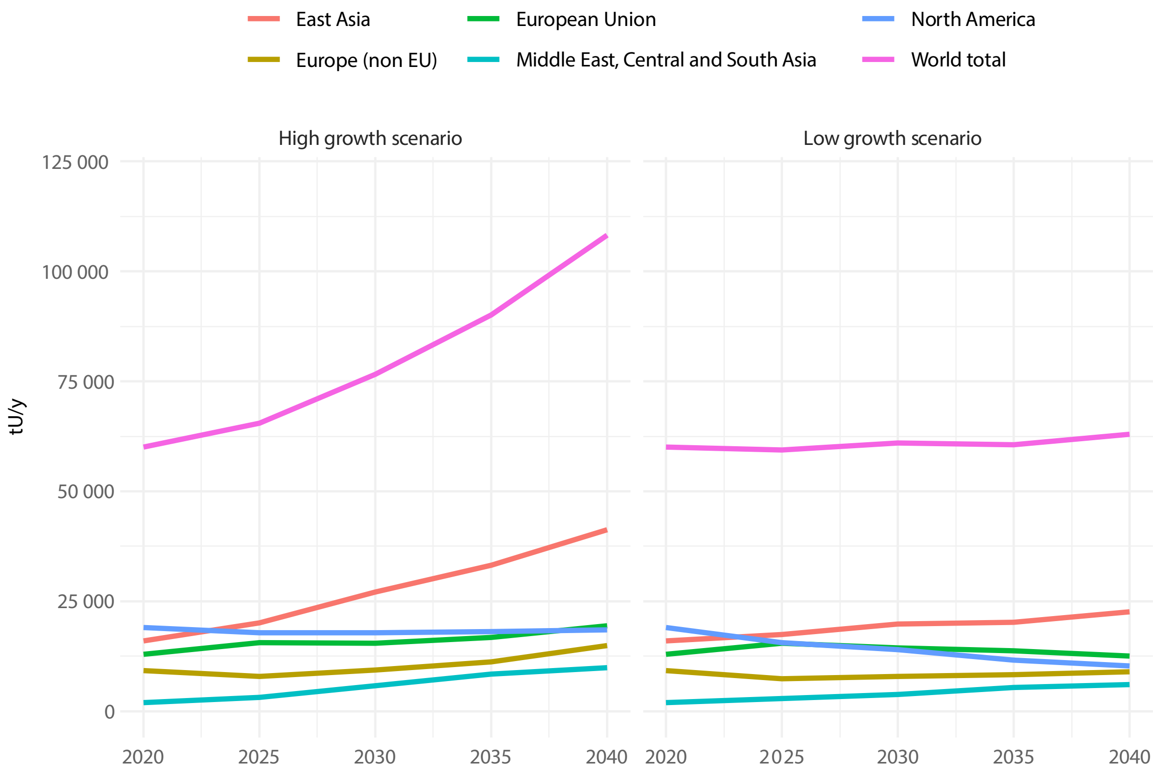
Table 2.5. **Annual reactor-related uranium requirements to 2040***

(tonnes U per year)

Region	2020	2025 low	2025 high	2030 low	2030 high	2035 low	2035 high	2040 low	2040 high
Africa	294	304	304	304	304	688	1 392	1 232	1 872
Central and South America	619	560	576	784	784	720	1 056	1 120	1 712
East Asia	16 039	17 408	20 080	19 824	27 056	20 176	33 248	22 560	41 296
Europe (non-EU)	9 244	7 328	7 904	7 904	9 376	8 272	11 232	9 008	14 880
European Union	12 942	15 440	15 584	14 368	15 456	13 696	16 736	12 592	19 360
Middle East, Central and South Asia	1 945	2 816	3 200	3 808	5 728	5 408	8 448	6 032	9 888
North America	19 031	15 552	17 872	13 968	17 888	11 584	18 048	10 336	18 464
Pacific	0	0	0	0	0	0	0	0	0
South Eastern Asia	0	0	0	0	0	0	0	160	800
World Total	60 114	59 408	65 520	60 960	76 592	60 544	90 160	63 040	108 272

* NEA/IAEA estimate.

Figure 2.3. **Projected annual reactor-related uranium requirements to 2040**
(low and high projections)



Uranium supply and demand relationship

Uranium supply has met demand for decades, and there have been no supply shortages since the last edition of this report. However, a number of different sources of supply are required to meet demand. The largest is the primary production of uranium. Secondary sources of uranium include stockpiles of natural and enriched uranium, blending down weapons-grade uranium, reprocessing of spent fuel, underfeeding and the re-enrichment of depleted tails.

Primary sources of uranium supply

Uranium was produced in 17 countries in 2020 and 2021, with total global production amounting to 47 342 tU in 2020 and 47 472 tU in 2021 (see Table 1.18).

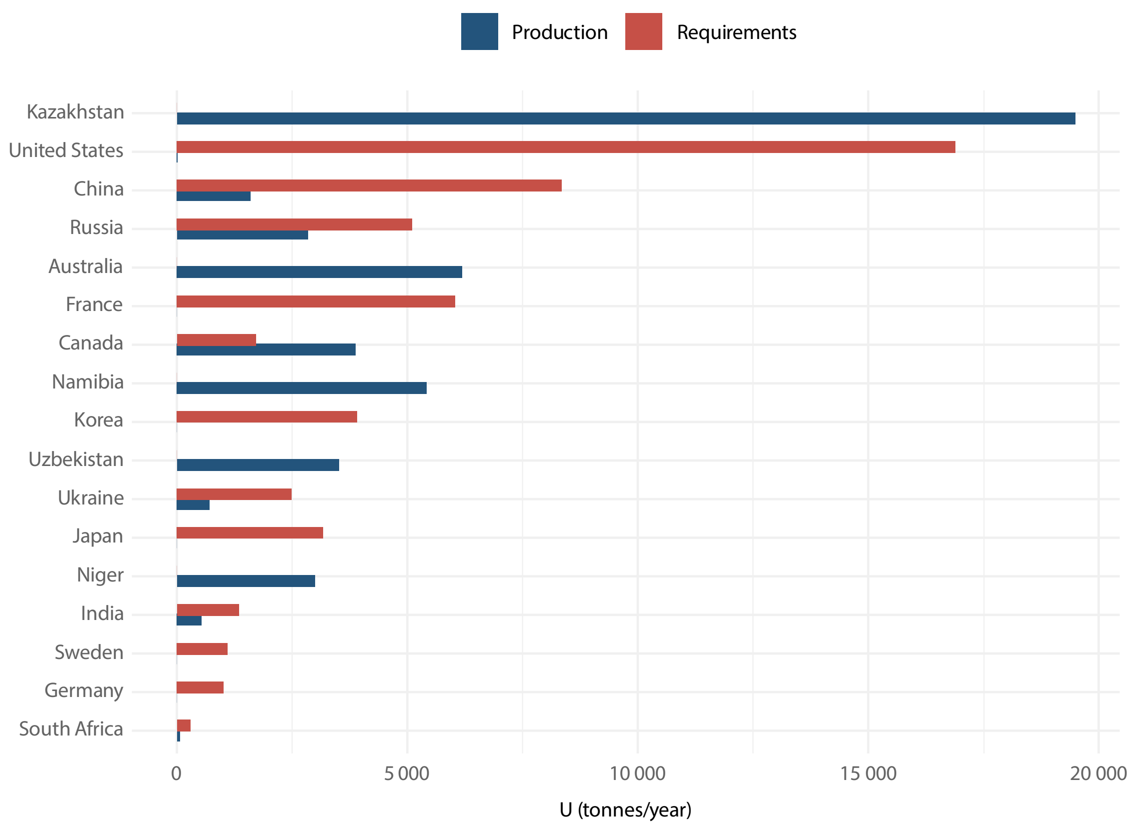
Kazakhstan is the world's largest producer and remained in that position through 2021, being responsible for over 46% of world uranium production that year. The top six producing countries in 2021 (Kazakhstan, Namibia, Canada, Australia, Uzbekistan and Russia, by order of production) accounted for 88% of world production, while 99% of world uranium production took place in 10 countries (Kazakhstan, Namibia, Canada, Australia, Uzbekistan, Russia, Niger, China, India and Ukraine).

The COVID-19 pandemic triggered a decrease in the supply of uranium as the main producers suspended uranium operations and temporarily closed their mines. Nevertheless, the suspension of uranium mining activity is not expected to disrupt the performance of nuclear power reactors in the near term as utilities and fuel cycle producers hold significant stocks (see section below on stocks and inventories).

Of all countries with installed nuclear generating capacity, only Canada produced enough uranium to meet domestic requirements (see Figure 2.4) in 2021. All other countries with nuclear power must make use of imported uranium or secondary sources and, as a result, the international trade of uranium is a necessary and established aspect of the uranium market. Given the uneven geographical distribution between producers and consumers, the safe and secure shipment of nuclear fuel will need to continue without unnecessary delays and impediments. The difficulties that some producing countries have encountered with respect to international shipping requirements and transfers to international ports have therefore always been a matter of concern.

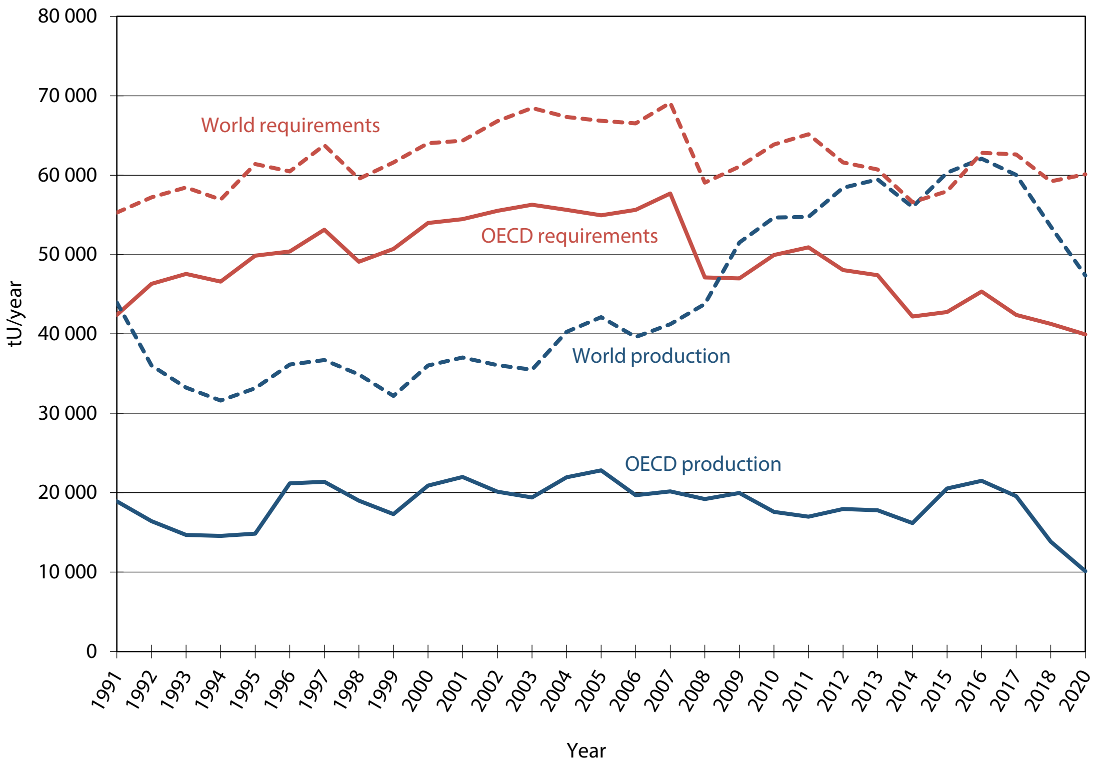
Figure 2.4. **Uranium production and reactor-related requirements for major producing and consuming countries**

(data as of 1 January 2021)



Because of the availability of secondary supplies, primary uranium production volumes have been significantly below world uranium requirements for some time. However, this trend has changed in recent years as production has increased and requirements have declined. In 2020, world uranium production provided around 74% of world reactor requirements. In OECD countries, the gap between production and requirements has changed little as both have declined in the past years. In 2020, production of 10 125 tU provided only around 25% of OECD requirements (39 941 tU). Remaining reactor requirements were met by imports and secondary sources.

Figure 2.5. **OECD and world uranium production and requirements**



Secondary sources of uranium supply

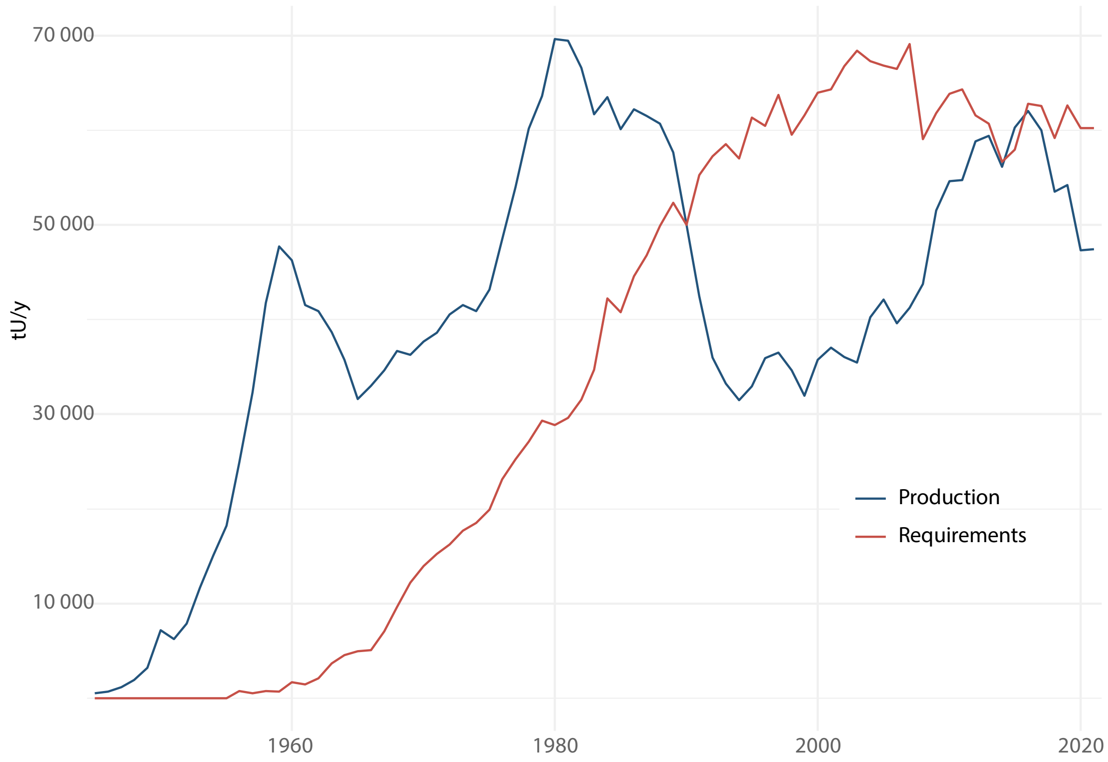
Uranium is unique among energy fuel resources in that, historically, a significant portion of demand has been supplied by secondary sources rather than direct mine output. These secondary sources include: stocks and inventories of natural and enriched uranium, both civilian and military in origin; nuclear fuel from the reprocessing of spent reactor fuels and from surplus military plutonium; underfeeding; and uranium produced by the re-enrichment of depleted uranium tails.

Natural and enriched uranium stocks and inventories

From the beginning of commercial exploitation of nuclear power in the late 1950s to 1990, uranium production consistently exceeded commercial requirements (see Figure 2.6). This was mainly the consequence of a lower than projected growth rate of nuclear generating capacity combined with high levels of production for strategic purposes. This period of overproduction created a stockpile of uranium potentially available for use in commercial power plants. After 1990, production fell well below demand and secondary supplies fed the market. Since 2008, requirements increased slightly before declining again in the last few years owing to unplanned reactor closures in Germany and Japan following the Fukushima Daiichi Nuclear Power Plant accident. Uranium production since 2007 has generally increased and has partially closed the gap between production and reactor requirements. The decline in requirements in 2018 was likely related to the reduced number of reactors being refuelled in Japan. More recently, producers have responded to the sustained uranium market downturn by temporarily shutting some operations and scaling back uranium production at other mines, causing a slight gap between supply and demand to reappear.

Figure 2.6. **World annual uranium production and requirements**

(1949-2021)

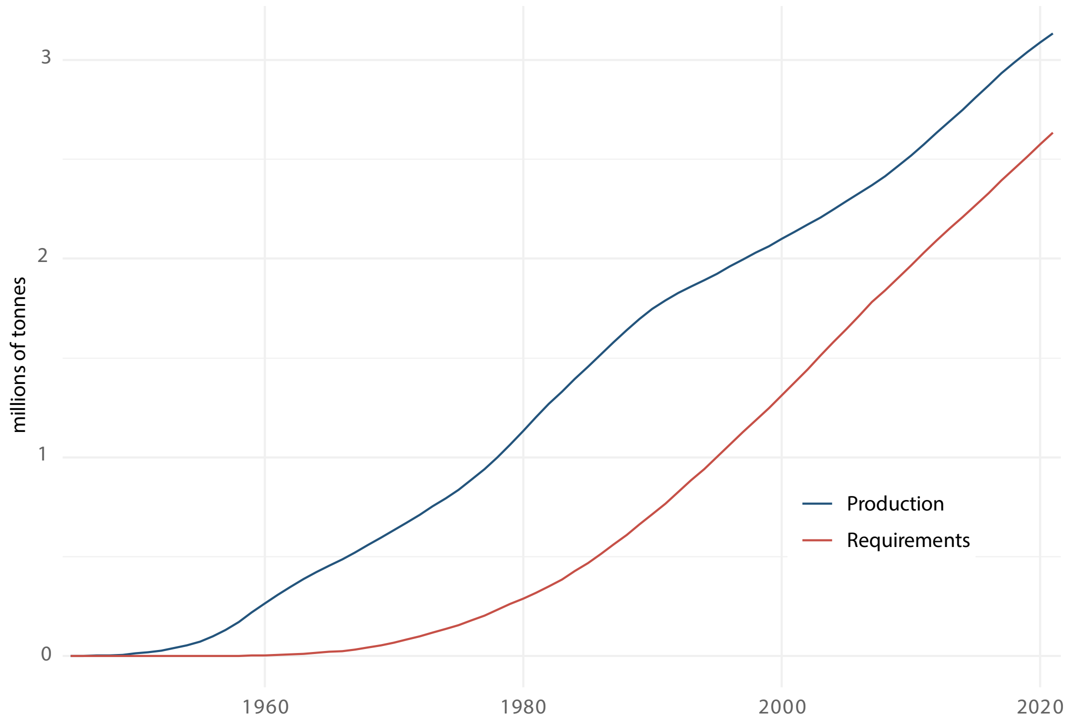


Following the political and economic changes in Eastern Europe and the former Soviet Union in the early 1990s, steps were taken to move towards the development of an integrated global commercial market. More uranium is now available from the former Soviet Union, most notably from Kazakhstan, but also from Russia and Uzbekistan. Despite these developments and more information being available on the amount of uranium held in inventory by utilities, producers and governments, uncertainties remain regarding the size and the mobility of these inventories, as well as the availability of uranium from other potential secondary supply sources. Although it is still early to analyse the long-lasting consequences in the global uranium market, it is clear that the geopolitical crisis triggered by Russia's invasion of Ukraine in February 2022 can create additional barriers to the exchange of Russia's stocks in the international market. These latter uncertainties combined with uncertainty about the desired levels of commercial inventories, continues to influence the uranium market.

Data from past editions of this publication, along with information provided by member countries, give a rough indication of the maximum level of the potential inventories commercially available when considering cumulative production and requirements for uranium at the global level. This leaves an estimated remaining stock of around 525 000 tU, which is a rough estimate of the upper limit of what could potentially become available to the commercial sector (see Figure 2.7). This base of already mined uranium has essentially been distributed into two sectors, with the majority used and/or reserved for the military and the remainder used or stockpiled by the civilian sector. However, since the end of the Cold War, increasing amounts of uranium, previously reserved for strategic purposes, have been released to the commercial sector.

Figure 2.7. **World cumulative uranium production and requirements**

(1949-2021)



Civilian inventories include strategic stocks, pipeline inventory and commercial stocks available to the market. In recent years, material held by financial investors has been a part of the inventory. Utilities are believed to hold the majority of commercial stocks because many have policies that require them to carry the equivalent of one to several years of natural uranium requirements. Despite the importance of this secondary source of uranium, information about the size of these stocks is limited because few countries are able or willing, because of confidentiality concerns, to provide detailed information on stockpiles held by producers, consumers or governments.

In the United States, as of 1 January 2021, total commercial inventories (utilities and producers' stocks) were 54 483 tU (EIA, 2021). Around 76% of the commercial inventories were held by owners and operators of commercial reactors. Enriched uranium inventories held by utilities (including fuel elements in storage) in 2021 (around 20 145 tU) were up around 8% from their 2019 values, whereas natural uranium inventories held by utilities (including UF_6 in storage) have decreased 10% from their 2019 values (EIA, 2021).

In the European Union, uranium inventories (still including UK inventories) held by utilities at the end of 2020 totalled 42 396 tU, enough for an average of more than two years' fuel supply, and down around 7% since the end of 2018 (ESA, 2020 and 2021) (see Table 2.6).

Uranium requirements are growing rapidly in East Asia, in particular in China. By 2040, demand in this region is expected to be roughly equivalent and even surpass (in the high case scenario) that of North America and the EU together. Questionnaire responses received during the compilation of this edition revealed little about national inventory policies in the East Asia region. Based on import statistics, it is estimated (WNA, 2021) that as of 1 January 2021, China had an accumulated inventory of over 129 000 tU, while India held an inventory of 9 600 tU. It is assumed that these countries are holding these stocks in anticipation of increasing uranium requirements due to the significant number of reactors under construction and planned, and also for strategic purposes.

Table 2.6. **Uranium inventories held by EU and US utilities**

(tonnes natural U equivalent at the end of the year)

Year	Inventories held by EU utilities	Inventories held by owners and operators of the US nuclear power plants
2015	51 892	46 589
2016	51 514	49 217
2017	49 004	47 635
2018	45 342	42 759
2019	42 912	43 385
2020	42 396	41 024
2021	36 810*	41 732[(a)]

Source: ESA Annual Report, 2019, 2020, 2021; US EIA Uranium Marketing Annual report 2019, 2020, 2021.

* Note the EU data no longer includes UK inventories as of 2021 figures.

a) Preliminary data.

In recent years, commercial entities other than utilities have been holding quantities of uranium for investment purposes. Although commercially confidential, variable and largely dependent on uranium price dynamics, the US Energy Information Administration notes that US-based traders and brokers held about 9 600 tU as of 1 January 2021 (EIA, 2021), an almost threefold increase compared to the levels at the end of 2016.

Excess uranium inventories held by the US government were last reported in 2013. At that time, the government possessed 56 031 tU, which includes 17 596 tU of uranium concentrates, 12 485 tU of enriched uranium, and 25 950 tU of depleted uranium. In May 2014, the US Government Accountability Office reported that as of 31 December 2012, the US Department of Energy maintained an excess uranium inventory of 29 tU in highly enriched uranium (HEU); 48 tU in low-enriched uranium (LEU); 12 939 tU in natural uranium; 114 000 tU in high-assay depleted uranium tails; and 387 000 tU in low-assay depleted uranium tails. A DOE Secretarial Determination must be made in advance of sales or transfers of these inventories in order to provide assurance that the transactions will not have an adverse material impact on the domestic uranium mining, conversion or enrichment industries.

In the calendar year 2015, the DOE Secretarial Determination authorised the transfer of up to 2 000 tU to DOE contractors for clean-up services at the Portsmouth gaseous diffusion plant and up to 500 tNatU to the National Nuclear Security Administration (NNSA) for blending down HEU to low-enriched uranium (LEU). Other transactions involved the transfer of up to 9 082 t of depleted uranium (DU) to Energy Northwest in 2012 and 2013, the majority of which would be enriched for use in the company's power reactor and the remainder sold to TVA as part of a commercial transaction to support future power generation and tritium production from 2013 through 2030. In 2016, the US DOE Secretary determined that exchange of LEU to HEU down-blending services serves national security purposes and that in this case the transfers no longer require a Secretarial Determination.

In 2017, the US DOE issued a new Secretarial Determination that further reduces transfers of material to support Portsmouth gaseous diffusion plant clean-up work to 1 200 tU as natural UF_6.

In 2018, the Secretary of Energy issued a determination covering the transfer of low-enriched uranium in support of the tritium production mission. The Secretarial Determination establishes the national security purpose of these transfers, therefore these uranium transfers were conducted under Section 3112(e)(2) of the USEC Privatisation Act of 1996.

Large stocks of uranium, previously dedicated to the military in both the United States and Russia, have become available for commercial applications, bringing a significant secondary source of uranium to the market. Despite the programmes outlined below, the remaining inventory of HEU and natural uranium held in various forms by these governments is significant, although official figures on strategic inventories are not available. If additional disarmament initiatives are undertaken to further reduce strategic inventories, several years of global supply of NatU for commercial applications could be made available.

HEU from Russia

Russia and the United States signed a 20-year, government-to-government agreement in February 1993 for the conversion of 500 t of Russian HEU from nuclear warheads to LEU suitable for use as nuclear fuel (referred to as the Megatons to Megawatts agreement). The United States Enrichment Corporation (USEC), the executive agent for this agreement, purchased the enrichment component of the LEU, about 5.5 million SWU per year, from Techsnabexport (TENEX) of Russia. Under a separate agreement, the natural uranium feed component of the HEU purchase agreement was sold under a commercial arrangement between three western corporations (Cameco, Areva and Nukem) and TENEX. Deliveries under this government-to-government agreement were finalised at the end of 2013. As of 2022, it is clear that the changing geopolitical scene will see western utilities seeking western uranium enrichment services and fuel providers.

HEU from the United States

As of June 2015, the US DOE reported 15 t of unallocated HEU. Following the current campaign, the National Nuclear Security Administration (NNSA) plans to conduct a HEU down-blending offering for tritium (DBOT) programme in the fiscal years 2019-2025.

Fuel banks

Efforts by governments and international agencies have also resulted in actions to create nuclear fuel banks – another form of inventory.

Driven by rising energy needs, non-proliferation and waste concerns, governments and the IAEA have made a number of proposals aimed at strengthening non-proliferation by establishing multilateral enrichment and fuel supply centres.

In December 2010, the first LEU reserve was inaugurated in Russia at the International Uranium Enrichment Centre in Angarsk under IAEA auspices. This LEU reserve is comprised of 120 t LEU in the form of UF_6 enriched to 2%-4.95% ^{235}U. Under IAEA safeguards, the reserve will be made available to IAEA member states whose supplies of LEU are disrupted for reasons unrelated to technical or commercial issues. The LEU reserve is not intended to distort the functioning of the commercial market, but rather to reinforce existing market mechanisms of member states.

Also in December 2010, the IAEA Board of Governors authorised the IAEA Director-General to establish a LEU bank to serve as a supply of last resort for nuclear power generation. The IAEA reserve is a backup mechanism to the commercial market in the event that an eligible member state’s supply of LEU is disrupted and cannot be restored by commercial means. In May 2015, Kazakhstan signed a draft agreement with the IAEA to host the IAEA LEU bank at the Ulba Metallurgical Plant. The IAEA LEU bank is a physical reserve of up to 90 metric tons of low-enriched uranium suitable to make fuel for a typical light water reactor. In 2018, the IAEA signed contracts to purchase LEU, paving the way towards the establishment of the IAEA LEU Bank in 2019. The IAEA LEU Bank was established and became operational on 17 October 2019. The establishment and operation of the IAEA LEU bank is fully funded by voluntary contributions. Donors have provided a total of USD 150 million to establish the LEU Bank and operate it for at least ten years. Donors include the Nuclear Threat Initiative (NTI), the United States, the European Union, the United Arab Emirates, Kuwait, Norway and Kazakhstan.

Nuclear fuel produced by reprocessing spent reactor fuels and surplus weapons-related plutonium

The constituents of spent fuel from nuclear power plants are a potentially substantial source of fissile material that could displace primary uranium production. When spent fuel is discharged from a commercial reactor, it is potentially recyclable since more than 90% of the original material is essentially made up of uranium-238, along with the plutonium and remaining uranium-235. The recycled plutonium can be reused in reactors licensed to use mixed oxide (MOX) fuel. The uranium recovered through reprocessing of spent fuel, known as reprocessed uranium (RepU), is not routinely recycled; rather, it is stored for future reuse.

The use of MOX has not altered world uranium demand since only a relatively small number of reactors are using this type of fuel. As of January 2021, there were 25 reactors, or around 5% of the world's operating fleet, licensed to use MOX fuel, in France, India, and the Netherlands (see Table 2.1). Reprocessing and MOX fuel fabrication facilities exist or are under construction in France, India, Japan and Russia. China is also building a pilot processing plant (200 tHM/yr) that is planned to be operational in the mid-2020s.

Following on basic research and MOX fuel fabrication for experimental reactors by the Japan Atomic Energy Agency (JAEA), Japan Nuclear Fuel Ltd (JNFL) began testing plutonium separation at the Rokkasho reprocessing facility in 2006. Japanese utilities began using MOX initially in fuel manufactured overseas. The use of imported MOX fuel was to be followed by the use of MOX produced at JNFL's MOX fuel fabrication facility (JMOX) adjacent to the Rokkasho reprocessing plant. JMOX construction began in 2010. Under the latest schedule, completion of the reprocessing plant has been put back to the first half of 2023 while the JMOX plant still needs to pass further checks on its construction plans before it can start operations, with currently no official date for the start of commercial operations.

Following the closure in 2003 of the Cadarache MOX fuel production plant in France and the MOX fuel plant in Belgium (Belgonucleaire) in 2006, the MELOX plant in Marcoule, France, was licensed in 2007 to increase annual production from 145 tHM to 195 tHM of MOX fuel (corresponding to 1 560 tNatU). Annual MOX production in France varies below this licensed capacity, in accordance with contracted quantities. Most of the MOX production is used to fuel French nuclear power plants (a total of about 120 t/yr; 960 tNatU) and the remainder is delivered abroad under long-term contract arrangements.

The Euratom Supply Agency (ESA) reported that the quantity of plutonium contained in the MOX fuel loaded into nuclear power plants in the EU was 5 308 kg in 2020, a slight increase over the 5 241 kg used in 2019 (ESA, 2021). Use of plutonium in MOX fuel reduced natural uranium requirements in the EU by an estimated 481 tU in 2020. In the 1996-2021 period, MOX fuel use in EU reactors has displaced a cumulative total of 25 922 tU through the use of 238.2 t of Pu (ESA, 2021). Since the great majority of world MOX use occurs in Western Europe, this figure provides a reasonable estimate of the impact of MOX use worldwide on uranium requirements during that period. Responses to the questionnaire provide some additional data on the production and use of MOX (see Table 2.7).

Uranium recovery through reprocessing of spent fuel, known as RepU, has been conducted in the past in several countries, including Belgium and Japan (see Table 2.8). It is now routinely undertaken only in France and Russia, principally because the production of RepU is a relatively costly endeavour, in part because of the requirement for dedicated conversion, enrichment and fabrication facilities. Available data indicate that it represents less than 1% of projected annual world requirements. Reprocessing could become a more significant source of nuclear fuel supply in the future if China successfully commercialises the process. It was reported that China planned to move beyond conducting research and development of reprocessing and recycling technologies to build and operate a large-scale commercial facility with a capacity of about 800 tHM/yr in order to achieve maximum utilisation of uranium resources, given the country's rapidly rising requirements. Since 2007, China and France have reportedly been discussing the possibility of France supplying a commercial-scale recycling facility.

Table 2.7. **MOX production and use**

	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
MOX production					
Belgium	523	0	0	523	0
France	24 397	870	635	25 902	NA
Japan	684	0	0	684	NA
MOX use					
Belgium	520	0	0	520	0
Japan	1 154	16	0	1 170	NA
Switzerland	1 407	0	NA	NA	NA

Table 2.8. **Reprocessed uranium production and use**

	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
RepU production					
France(a)	28 982	1 026	980	30 988	1 026
Japan	645	NA	NA	NA	NA
United Kingdom[(a)]	15 000	0	0	15 000	0
RepU use					
Belgium[(a)]	508	0	0	508	0
France	5 300	0	0	5 300	0
Germany[(a)]	0	0	0	0	0
Japan	217	0	0	217	0
Switzerland[(a)]	4 750	116	33	4 899	45
United Kingdom[(a)]	1 767	39	0	195	38

(a) See 2021 edition of *NEA Nuclear Energy Data*. Rows with countries that did not report any data in past years were suppressed.

MOX produced from surplus weapons-related plutonium

In September 2000, the United States and Russia signed the Plutonium Management and Disposition Agreement that committed each country to dispose of 34 t of surplus weapons-grade plutonium at a rate of at least 2 tonnes per year in each country, once production facilities are in place. Both countries agreed to dispose of the surplus plutonium by fabricating MOX fuel suitable for irradiation in commercial nuclear reactors.

In the United States, the MOX fuel was to be fabricated at the DOE's Savannah River complex in South Carolina. The DOE's NNSA awarded a contract for construction of the Mixed Oxide Fuel Fabrication Facility (MFFF) in 2001 and construction was officially started in 2007. In mid-2013, however, it was reported that the project had encountered technical difficulties and was running over budget. Since 2014, the project has seen progressive cuts to its funding as the DOE's National Nuclear Safety Administration embarked on a review of its plutonium disposition strategy. The DOE NNSA terminated the MOX project in October 2018. The facility was being built as part of the 2000 agreement with Russia whereby each country would dispose of 34 tonnes of weapons-grade plutonium. Russia – which had agreed to dispose of the material in fast reactors – suspended the agreement in October 2016.

The Russian MOX facility was reportedly abandoned in favour of burning excess plutonium in fast breeder reactors (WNA, 2017). A MOX fuel fabrication facility established by Mining and Chemical Combine (MCC) Zheleznogorsk, a Rosatom subsidiary, was officially started in 2015. Russia has no commercial reactors using MOX fuel, but its BN-800 fast neutron reactor will use MOX fuel. In August 2020, the MCC has received a five-year licence for the industrial production of MOX fuel for the Beloyarsk-4 BN-800 fast neutron reactor.

Uranium produced by re-enrichment of depleted uranium tails[2] *and uranium saved through underfeeding*

Depleted uranium stocks represent a significant source of uranium that could displace primary production. However, the re-enrichment of depleted uranium has been limited since it is only economic in enrichment plants with spare capacity and low operating costs.

The world stock of depleted uranium in 2021 is of around 1.2 million tonnes, with around 50 000 tonnes of depleted uranium being added yearly to already substantial stockpiles in the United States, Europe and Russia (WNA, 2021). Following the construction of new centrifuge enrichment facilities and declining demand since the Fukushima Daiichi Nuclear Power Plant accident, spare enrichment capacity is currently available, and it has been reported that tails assays are being driven downward at enrichment facilities to underfeed the centrifuge plants and create additional uranium inventory.

EU enrichers are now putting in place long-term strategies to manage enrichment tails remaining from enrichment activities, including deconversion of UF_6 to the more stable form U_3O_8. Currently, deconversion takes place in France, and Urenco UK is constructing a tails management facility.

In the United States, the DOE and the Bonneville Power Administration initiated a pilot project to re-enrich 8 500 tonnes of the DOE's enrichment tails inventory. Between 2005 and 2006, this project produced approximately 1 940 tU equivalent for use between 2007 and 2015 at Northwest Energy's 1 190 MWe Columbia generating station. In mid-2012, Northwest Energy and USEC, in conjunction with the DOE, developed a new plan to re-enrich a second portion of DOE's high assay tails. The resulting LEU is to be used to fuel Northwest Energy's Columbia generating station through 2028.

GE-Hitachi Global Laser Enrichment proposed to build and operate a tails processing plant using Silex laser enrichment technology on land adjacent to the closed Paducah gaseous diffusion enrichment plant. Successful development of laser enrichment could potentially result in an additional supply of uranium to the market in the longer term. However, GE-Hitachi Global Laser Enrichment recently announced plans to slow development of its laser technology because of poor market conditions. Some other commercial enrichment providers (e.g. Urenco) have indicated an interest in using centrifuge enrichment capacity for tails re-enrichment.

Additional information on the production and use of re-enriched tails is not readily available. However, the information provided in the questionnaire responses (see Table 2.9) indicates that its use has been limited in recent years.

2. Depleted uranium is the by-product of the enrichment process, with less ^{235}U than natural uranium. Normally, depleted uranium tails contain between 0.25% and 0.35% ^{235}U compared with the 0.711% ^{235}U found in nature.

Table 2.9. **Re-enriched tails production and use**

(tonnes of equivalent natural U)

Country	Total to end 2018	2019	2020	2021 (preliminary)
Production				
United States	5 678	0	0	0
Netherlands[(a)]	21 135	3 439	3 712	2 834
Use				
Belgium[(b)]	345	0	0	0
Finland	843	0	0	0
Sweden[(a)]	3 700	200	0	0
United States	1 940	0	0	0

NA = Data not available. (a) 2021 edition of *NEA Nuclear Energy Data*. (b) Purchased for subsequent re-enrichment.

Underfeeding

The potential for *underfeeding* of enrichment plants is also a source of secondary supply, which has become more important in the last few years. Underfeeding reduces the amount of uranium required to produce contracted quantities of enriched uranium and, in turn, creates a stockpile of uranium that can be sold. It is estimated that global underfeeding and tails re-enrichment contribute up to 6 000 tU of supply per year (WNA, 2019).

In recent years, secondary supply has shown a downward trend resulting from the end of the "Megatons to Megawatt" agreement. The level of secondary supply is currently around 10 500 tU/yr and is likely to decrease to about 6 000 to 7 000 tU/yr by 2040 (WNA, 2022).

Uranium market developments

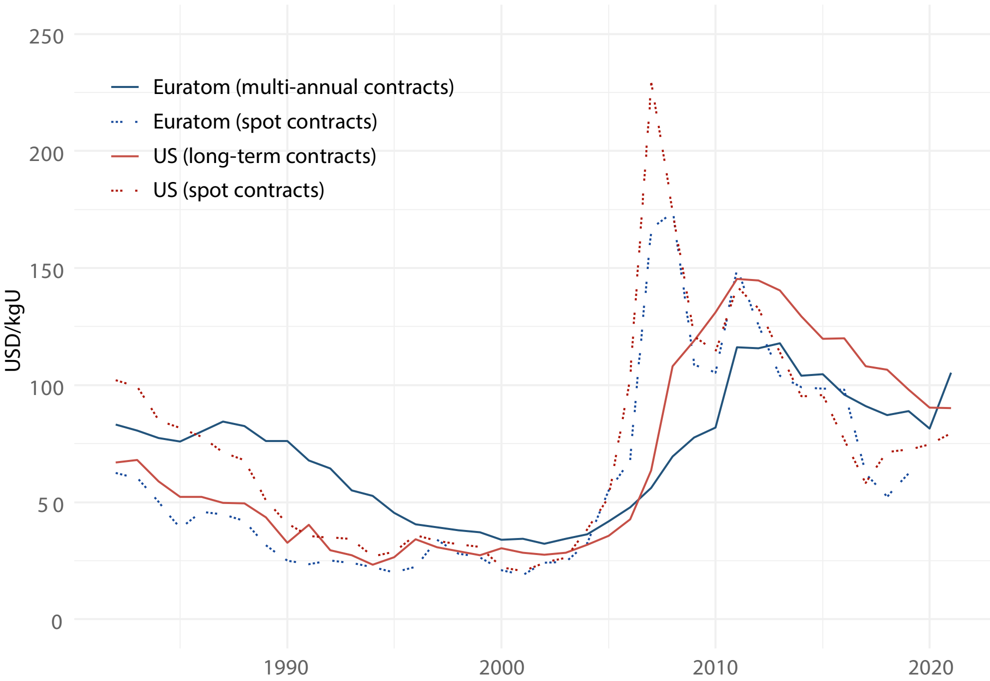
Uranium prices

Some national and international authorities (Australia, the United States and Euratom), publish price indicators to illustrate uranium price trends for both long-term and short-term (spot price) contract arrangements. Australian data record average annual prices paid for exports, whereas Euratom (ESA) and US data show costs of uranium purchases in a particular year. Canada and Niger published export prices for some years, but neither continue to do so. Figure 2.8 displays this mix of annual prices reported for both short-term and longer-term purchases and exports.

The overproduction of uranium, which lasted through 1990 (see Figure 2.6), combined with the availability of secondary sources, resulted in uranium prices trending downward from the early 1980s through the mid-1990s, bringing about significantly reduced expenditures in many sectors of the world uranium industry, including exploration and production. The bankruptcy of an important uranium trading company resulted in a modest recovery in prices from late 1994 through mid-1996, but the regime of low prices returned shortly thereafter.

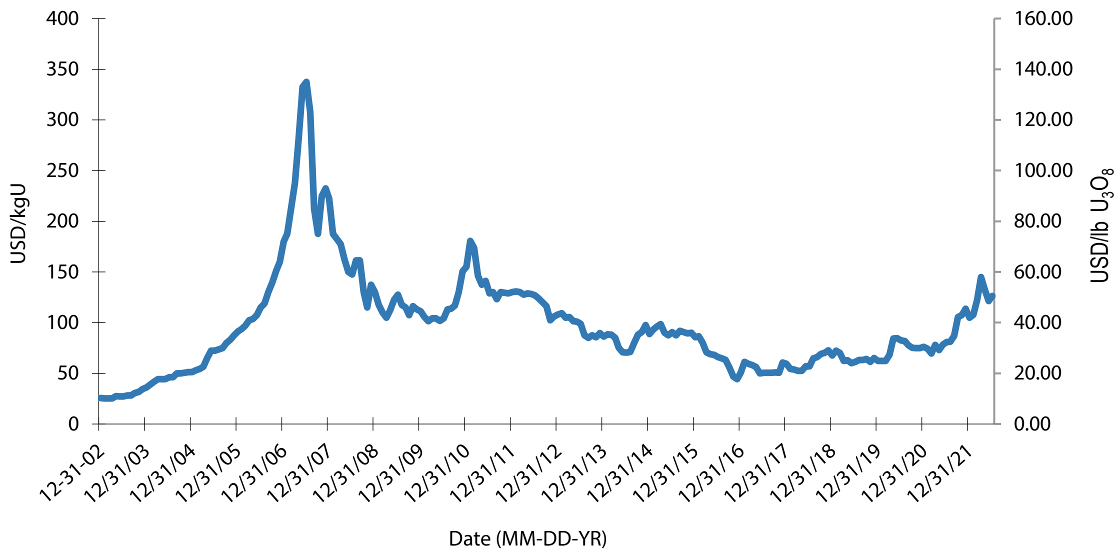
Beginning in 2002, uranium prices began to increase, eventually rising to levels not seen since the 1980s. They then rose more rapidly through 2005 and 2006, with spot prices reaching a peak through 2007 and 2008, and fell off rapidly, recovering somewhat in 2011 and declining in 2012 (see Figures 2.8 and 2.9). In contrast, EU and US long-term price indices continued to rise until 2011 before levelling off in 2012, and then started to decline until 2019. Fluctuations in these indicators do not rival the peak in the spot market in 2007 and 2008 or the degree of declining prices since 2011 since they reflect contract arrangements made earlier under different price regimes. The Australia average export price has generally followed the trend of other long-term price indices, but with greater variation since it is a mix of spot and long-term contract prices.

Figure 2.8. **Uranium prices for short- and long-term purchases and exports**
(1982-2021)



Source: ESA, 2021, EIA, 2021.

Figure 2.9. **Uranium spot price dynamics**
(TradeTech Exchange Value trend, 2002-2022)



Source: Trade Tech (www.uranium.info).

Note: The Exchange value is Trade Tech's judgement of the price at which spot and near-term transactions for significant quantities of natural uranium concentrates could be conducted as of the last day of the month.

In addition to this information from government and international sources, spot price indicators for immediate or near-term delivery (less than one year), which typically amount to 15% to 25% of all annual uranium transactions, are provided by the industry trade press, such as TradeTech and the Ux Consulting Company LLC (UxC). While the trend of increasing prices outlined above is evident for spot market transactions since 2002, and in particular after 2004, the spot price shows more volatility than long-term price indicators since 2006 (see Figure 2.9). In June 2007, the spot market price reached as high as USD 136/lb U_3O_8 (USD 354/kgU) before declining to USD 40.50/lb U_3O_8 (USD 105/kgU) in February 2010. It recovered to USD 72.25/lb U_3O_8 (USD 188/kgU) at the end of January 2011, before declining to USD 27/lb U_3O_8 (USD 70.2/kgU) at the end of 2018 (see Figure 2.9). In May 2019, the spot market price declined to USD 24/lb U_3O_8 (USD 62.4/kgU). In June 2021, the spot price was USD 32.40/lb U_3O_8 (USD 84.2/kgU).

A variety of factors have been advanced to account for the spot price dynamics between 2003 and 2020, including problems experienced in nuclear fuel cycle production centres that highlighted dependence on a few critical facilities in the supply chain, as well as changes in the value of the US dollar, the currency used in uranium transactions. The expected expansion of nuclear power generation in countries such as China, India and Russia, combined with the recognition by many governments of the role that nuclear energy can play in enhancing security of energy supply, contributed to the strengthening market through 2007. The influence of speculators in the market helped accelerate upward price movement at this time. The downturn in the spot price since June 2007 began with the reluctance on behalf of traditional buyers to purchase at such high prices and the global financial crisis that stimulated sales by distressed sellers needing to raise capital.

In late 2007, the uranium spot price began a gradual decline that settled in 2009 in a range between USD 40/lb U_3O_8 (USD 104/kgU) and USD 50/lb U_3O_8 (USD 130/kgU). Proposed US government inventory sales appeared to offset rising demand as government programmes in China and India to increase nuclear generating capacity began to be implemented. In the second half of 2010, the spot price began to rally once again on news that China was active in the long-term market, stimulating speculative activity on perceptions of tightening supply-demand. However, the Fukushima Daiichi Nuclear Power Plant accident precipitated an initial rapid decline in price. Projects to increase uranium production, implemented before the accident, resulted in increasing production even as demand weakened and the market became saturated with supply, putting further downward pressure on prices through to the end of 2019. In addition, the excess uranium inventories and the decline in uranium needs as a result of the substitution of enrichment (underfeeding) contributed to the downdraught in uranium prices. Significant uranium production cuts have been made during 2018-2019 (e.g. McArthur River mine in Canada) contributing to high spot purchasing levels as producers and traders bought material to cover near-term delivery commitments. The significant rise in the spot price seen in March and April 2020 was precipitated largely by additional curtailments to primary production brought on by the COVID-19 pandemic.

The uranium market was also impacted by macroeconomic trends. The strengthening of the US dollar in recent years, especially in relation to the currencies of major uranium producers (e.g. Canadian dollar, Kazakh tenge, Russian rouble and South African rand) contributed to the uranium price volatility. Non-US mining companies have benefited from US dollar appreciation against these currencies, as most of their operating costs, including labour, are in their domestic currencies. This allowed them to keep operating the mines despite falling uranium market prices, expressed in US dollars.

The uranium market could be further affected by developments on both the demand and supply side. Demand factors include Japanese restarts and successful global new builds. Key considerations on the supply side include uranium production levelling off in the short term as well as possible limitations on government inventories. When looking at the longer-term outlook, there is a general agreement that nuclear growth is likely to continue. Asia and the Middle East are the most critical markets for new reactors, and new uranium production will be needed in the coming decades. However, new uranium supply capacity would need the right price signals for producers to make investments.

Policy measures in the EU and uranium prices

Since its establishment in 1960 under the Euratom Treaty, the Supply Agency of the European Atomic Energy Community (ESA) has pursued a policy of diversification of sources of nuclear fuel supply to avoid overdependence on any single source. Within the European Union, all uranium purchase contracts by EU end users (i.e. nuclear utilities) must be concurred by the ESA. Based on its contractual role and its close relations with industry, the ESA monitors the market with a particular focus on supplies of natural and enriched uranium to the EU. The ESA continues to stress the importance of maintaining an adequate level of strategic inventory and using market opportunities to increase inventories, where possible. It also recommends that utilities cover the majority of their needs under long-term contracts with diverse suppliers and it continues to promote transparency and predictability in the market.

Uranium purchased for EU reactors came from diverse sources in 2021 (ESA, 2021). The top five providers amounted to more than 96% of all uranium purchased by EU utilities. In decreasing order of percentage of uranium provided, these were: Niger (24%), Kazakhstan (23%), Russia (20%), Australia (16%), and Canada (14%). Uranium of European origin delivered to EU utilities covered less than 2% of the EU's total purchases (ESA, 2021).

Since uranium is sold mostly under long-term contracts and the terms are not made public, the ESA traditionally publishes two categories of natural uranium prices on an annual basis, i.e. multi-annual and spot, both being historical prices calculated over a period of many years. With at least some uranium market participants seeking greater price transparency, the ESA introduced a new natural uranium multi-annual contracts index price (MAC-3) in 2009. This index price, developed to better reflect short-term changes in uranium prices and to more closely track market trends, is a three-year moving average of prices paid under new multi-annual long-term contracts for uranium delivered to EU utilities in the reporting year (see Table 2.10).

Table 2.10. **ESA average natural uranium prices**

(2011-2021)

Year	Multi-annual contracts		Spot contracts		New multi-annual contracts (MAC-3)	
	EUR/kgU	USD/lb U_3O_8	EUR/kgU	USD/lb U_3O_8	EUR/kgU	USD/lb U_3O_8
2011	83.45	44.68	107.43	57.52	100.02	53.55
2012	90.03	44.49	97.80	48.33	103.42	51.11
2013	85.19	45.32	78.24	39.97	84.66	43.25
2014	78.31	40.02	74.65	38.15	93.68	47.87
2015	94.30	40.24	88.73	37.87	88.53	37.78
2016	86.62	36.88	88.56	37.71	87.11	37.09
2017	80.55	35.00	55.16	23.97	80.50	34.98
2018	73.74	33.50	44.34	20.14	74.19	33.70
2019	79.43	34.20	55.61	23.94	80.00	34.45
2020	71.37	31.36	***	***	75.51	33.17
2021	89.00	40.49	***	***	92.75	42.19

Source: ESA, 2019, 2020, 2021.

Note *** In 2020 the ESA spot price was not calculated because there were not enough transactions (less than 3) to calculate the index. Before 2021: data for EU-27 + UK.

Since uranium is priced in US dollars, fluctuation of the EUR/USD exchange rate influences the level of the price indices calculated. The average EUR/USD rate in 2021, according to the European Central Bank, stood at 1.18, which was 3.5% higher than in the previous year.

Supply and demand to 2040

Market conditions are the primary driver of decisions to develop new or expand existing primary production centres. Market prices have generally increased since 2003, and plans for increasing production capability continued through 2021. A number of countries, notably Australia, Brazil, Canada, China, India, Namibia, Niger, Russia and South Africa, have plans for significant additions to future production capability. Some other countries, notably Botswana, Denmark/Greenland, Finland, Mauritania, Mongolia and Tanzania are working towards producing uranium in the near future. These developments are important as global demand is projected to increase in the longer term, and secondary sources are expected to decline somewhat in availability.

However, with rising mining and development costs and the long pause in nuclear development following the Fukushima Daiichi Nuclear Power Plant accident, along with the continuing decline of market prices through 2019, delays in some of the planned mine developments have been announced. Uranium production has also slowed at a number of existing facilities because of poor market conditions. The most significant of these changes was the suspension of Canada's McArthur River mine and Key Lake mill, following a series of production cuts to Kazakh production, a reduction to Niger uranium output, and cessation of production at Langer Heinrich project in Namibia. Meanwhile, many ISL mines in the United States are facing a situation in which no new capital is being invested into developing new wellfields. In addition, over the first part of 2020, the COVID-19 pandemic significantly impacted production, with many mines temporarily closed. An improvement in uranium market conditions should see at least some of the delayed projects or the mines in care and maintenance reactivated in order to ensure supply to a growing global nuclear fleet. Since several of these projects have advanced through regulatory and other development steps, the time required to bring these facilities into production should be reduced overall, and production will likely be able to respond more rapidly to increasing demand.

Despite some uncertainties and challenges in raising investment for mine development, producers have moved to increase production capability in recent years and governments are laying the groundwork (e.g. legislation and regulations) for mine development in countries that have not previously hosted uranium production. However, should uranium demand increase as projected, producers would still face a number of significant and unpredictable issues in bringing new production facilities on stream, including geopolitical and policy factors (e.g. from the ban on new uranium mine development in Western Australia, to terrorist attacks in Niger and a global pandemic), technical challenges and risks at some facilities, the development of more stringent regulatory requirements and heightened expectations of governments hosting uranium mining (e.g. increased taxes and contributions to regional socio-economic development).

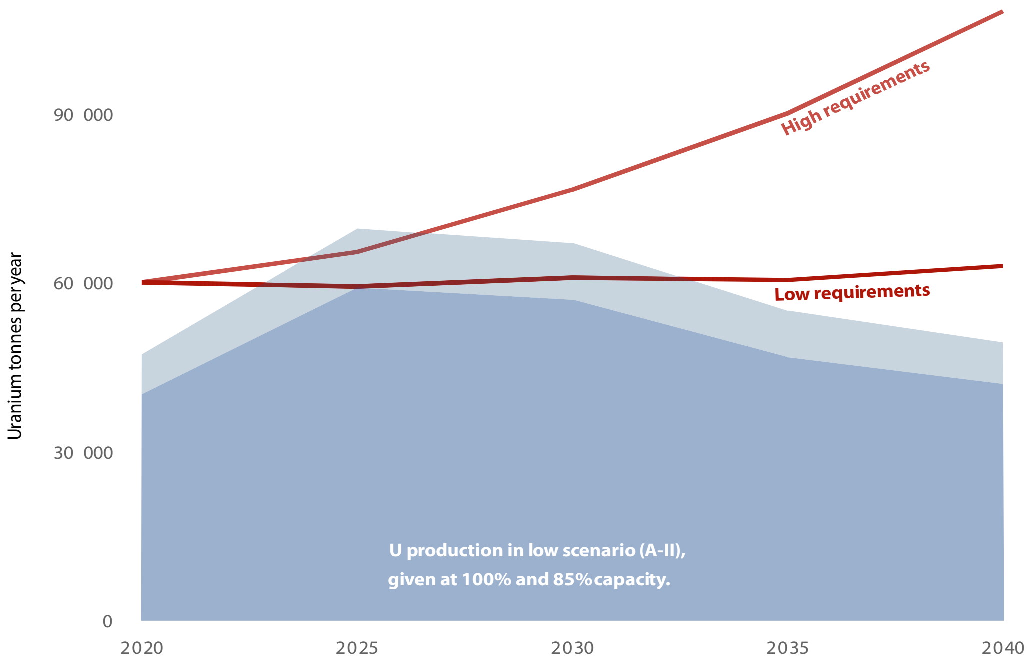
As reactor requirements are projected to rise through 2040, production capability is also projected to expand (see Figure 2.10). As noted earlier, secondary sources can be expected to continue to be a source of supply for some years, despite a general downward trend.

If all existing and committed mines (A-II) produce at or near stated production capability, high case demand is projected to be met through 2025 (without taking into account the secondary supplies). If planned and perspective production capability is included (B-II), high case demand requirements are projected to be met through 2035. Planned capability from all existing and committed production centres is currently projected to cover around 78% of low case requirements through 2040 and about 46% of high case requirements in 2040. With the inclusion of planned and prospective production centres, primary production capability would more than satisfy low case requirements through 2040, would cover all high case demand through 2035 and around 91% of the high case demand in 2040.

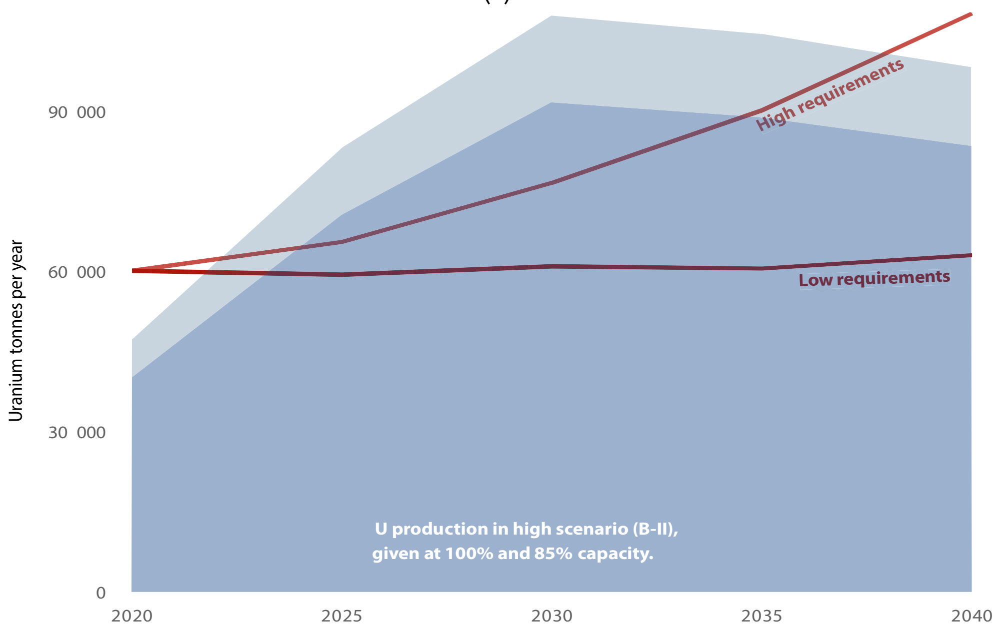
However, real mine production is rarely more than 85% of a mine's production capability and several challenges will need to be overcome in order for all planned and prospective uranium projects to be successfully brought into production. Figure 2.10 also gives, therefore, an overview of the supply/demand relationship with global production capability at 85% of mine production capability. In this case, a gap is identified for the high case reactor requirements scenario starting with 2025 and can be filled with secondary supply or new projects.

Figure 2.10. **Projected world uranium production capability to 2040 (supported by identified resources at a cost of <USD 130/kgU) compared with reactor requirements**

(a)



(b)



Source: Tables 1.23 and 2.5.

Figure a) illustrates the A-II case (production capability of existing, idled and committed centres supported by RAR and inferred resources recoverable at <USD 130/kgU). Figure b) illustrates the B-II case (production capability of existing, idled, committed, planned and prospective centres supported by RAR and inferred resources recoverable at <USD 130/kgU). Both figures illustrate two production capacities per case: the light shaded area represents 100% of production capacity, the darker shade represents 85% of the production capacity.

Note that figures do not include the secondary supply forecast, which has in the past filled the gap between primary production and demand.

The total identified uranium resource base in 2021 (see Table 1.1) is adequate to meet even high case projections of growth in nuclear generating capacity. Meeting high case demand requirements would consume by 2040 around 26% of the total 2021 identified recoverable resource base at a cost of <USD 130/kgU (USD 50/lb U_3O_8). If lower cost resources are considered (<USD 80/kgU; USD 30/lb U_3O_8), the high case demand would correspond to around 80% of the identified recoverable resource base by 2040. With the appropriate market signals, as significant new nuclear generating capacity is added, additional resources of economic interest are likely to be identified with additional exploration efforts.

The gap between production and requirements from 2008 (and earlier) to 2014 has been met by drawing down secondary supplies. In 2014, producers almost closed the gap between world production and reactor requirements, albeit with requirements temporarily depressed owing to reactor closures and idling of reactors in Japan following the Fukushima Daiichi Nuclear Power Plant accident. However, following the production cuts and the reductions due to the COVID-19 pandemic in 2020, a gap between demand and primary supply appeared again. Furthermore, it should be noted that production capability is not production. Maintaining production at the level required to meet reactor requirements in the coming years, particularly in light of uncertainties related to the COVID-19 pandemic and depressed market prices for uranium, will be a challenge.

World production has varied between 70% and 90% of full production capability since 2008. In addition, delays in the establishment of new production centres can reasonably be expected, especially in the prevailing risk-averse investment environment. As always, technical and geopolitical challenges in the operation and development of mine and mill facilities will need to be effectively dealt with. These factors can be expected to reduce and/or delay development of planned and prospective centres. Although the industry has responded vigorously to the market signal of generally higher prices since 2003, compared to the previous 20 years, additional primary production will likely be required. As secondary sources of uranium are generally expected to decline somewhat in availability, reactor requirements will have to be increasingly met by primary production. Therefore, despite the significant additions to production capability reported here, bringing facilities into production in a timely fashion remains important. To do so, strong uranium market conditions will be fundamental in bringing the required investment to the industry.

A key uncertainty of the uranium market continues to be the availability and the mobility of secondary sources, particularly the level of stocks available and the length of time remaining until those stocks are exhausted. However, the possibility that at least a portion of the potentially large inventory (including from the military) will continue to make its way to the market after 2022 cannot be discounted. These uncertainties complicate investment decisions on new production capability. Another limiting factor for investment decisions is that uranium demand outlook in the near- to medium-term is driven primarily by the large number of reactors that are scheduled to close (e.g. in Europe and the United States), which offsets the growth from new nuclear power plants in other countries (e.g. China).

It is clear that the generally stronger market of the 2003-2011 period, compared to the last two decades of the 20th century, has driven exploration activity, building up a significant base of uranium resources. However, history shows that periods of low prices for uranium and reliance on secondary supplies have had dramatic impacts on the industry in terms of consolidation of producers and significant reductions in primary production capability.

The long-term perspective

Global uranium demand is fundamentally driven by the number of operating reactors in the world, which ultimately is driven by the demand for electricity. In turn, the role that nuclear energy will play in helping meet projected electricity demand (i.e. the number of operating reactors) will depend on government policy decisions that affect nuclear power plant development and on how effectively a number of factors discussed earlier are addressed (e.g. economics, safety, security of energy supply, security of supply chain, waste disposal, environmental considerations). The extent to which nuclear power will be part of future low-carbon electricity mixes thus also depends on ongoing energy policy discussions in countries the world over.

All credible models show that nuclear energy has an important role to play in decarbonisation and global climate change mitigation efforts (e.g. NEA, 2022; IEA, 2021) as an established large-scale, low-carbon emissions energy source. However, industry must first receive clear and consistent policy support for existing and new capacity development, with nuclear also included in clean energy incentive schemes schemes, as well as indications that a supply of uranium is readily available at least 50 years or more into the future. Recognising the importance of the security of supply, reliability and predictability that nuclear power offers and promoting incentives for all types of low-carbon electricity production are key conditions for a faster deployment of nuclear power. The expansion of nuclear power is mainly policy-driven and faces challenges due to large upfront capital costs, complex project management requirements and often long permitting processes. Without actions to provide more support for nuclear power, global efforts to mitigate climate change will become significantly harder and more costly (IEA, 2019), as it is clearly established that achieving net zero globally will be harder without nuclear (IEA, 2022).

The NEA study, *Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders* (NEA, 2020b) highlights that while industry has made major efforts in terms of organisational restructuring and integration of a number of recent technological advances, governments also have a role regarding significant construction costs and risk reductions by committing to the next set of new build projects. With several projects under completion in OECD countries, the next decade offers opportunities to capitalise on the experience accumulated to improve the economic performance of both traditional large reactors and new innovative designs.

As the recent NEA report *Meeting Climate Change Targets: The Role of Nuclear Energy* (NEA, 2022) notes, rapid build-out of new nuclear energy is possible but requires a clear vision and plan. Experience shows that under the right policy frameworks and a robust programmatic approach, nuclear energy can be a low-carbon technology with rapid delivery times. This was the case historically for countries such as France and Sweden and jurisdictions such as Ontario in Canada that have both decarbonised their electricity mix in less than two decades with nuclear energy and hydropower.

Several alternative uses of nuclear energy also have the potential to increase nuclear power installation worldwide, including desalination and heat production for industrial and residential purposes. Cogeneration, combining industrial heat applications with electricity generation, is not a new concept; some of the first civilian reactors in the world were used to supply heat as well as electricity. District heating using heat generated in reactors has been used in some countries for decades. Industrial process heating has also been used and there is potential for further development, but the extent to which nuclear reactors will be used for such applications will depend on the economics of heat transport, international pressure to reduce CO_2 emissions and national desires to reduce dependence on imported fossil fuels, as well as competition with alternative heat or combined heat and power (CHP) technologies (IAEA, 2019b).

The prospect of using nuclear energy for desalination on a large scale is attractive since desalination is an energy intensive process that can make use of either the heat from a nuclear reactor and/or the electricity produced. About one-third of the world's population lives in water-stressed areas, with a majority in Sub-Saharan Africa, the Middle East and South Asia, and with climate change, access to fresh water could become increasingly challenging (IAEA, 2020). In recent years, several governments have been actively evaluating the possibility of using nuclear energy for desalination (e.g. China, Jordan, Libya and Qatar), building on experience gained through the operation of integrated nuclear desalination plants in India, Japan and Kazakhstan. The advanced nuclear reactors that are under development as Generation IV reactors will have higher outlet temperatures and will thus be more suited to supplying heat for a larger range of industrial processes.

Cogeneration applications of nuclear energy are most likely to develop if nuclear cogeneration is more economical than the technical solutions it replaces, essentially gas-fired production of steam and electricity. Because of its large upfront capital costs and economies of scale, nuclear energy might be appropriate (i.e. competitive against fossil fuel applications) for significant combined heat and electricity demand. Small modular reactors (SMRs) may certainly address other market segments if they demonstrate their competitiveness. A solid understanding of the economics of nuclear cogeneration, including the associated system costs, is therefore essential (NEA, 2022b).

Energy use for transport, which is projected to continue to grow rapidly over the coming decades, is also a major source of greenhouse gas emissions. Both electric and hydrogen-fuelled vehicles are seen as potential replacements for those powered by fossil fuels. Nuclear energy offers baseload electricity production that could be used to power electric vehicles; it also has the potential of producing hydrogen on a massive scale that could make this alternate energy carrier available with significantly less greenhouse gas emissions compared to current methods of hydrogen production.

There is increasing interest in SMRs in both established nuclear countries (e.g. Argentina, Canada, the United States), and in newcomer countries in Europe, the Middle East, Africa and Southeast Asia. SMRs, with capacities generally in the range of 30-300 MWe, could be suitable for areas with small electrical grids and for deployment in remote locations. SMRs offer smaller upfront investment costs and reduced financial risks compared to larger reactors typically being built today (1 000-1 700 MWe) and may be deployed as alternatives to larger nuclear power plants in locations where such plants cannot be built, or to fossil fuel-fired plants of similar sizes.

The developments in design and technology, technical feasibility, the economic aspects and the factors affecting the competitiveness of SMRs are described in various reports (NEA, 2021a; IAEA, 2020a; NEA, 2016). A large number of SMR designs are reported to be under different stages of development (more than 70 designs reported). Many are still at the conceptual design phase, with some at the licensing phase and some already under construction (in Argentina and in China). Russia connected the world's first floating nuclear power plant (KLT-40), Akademik Lomonosov, to the grid and started commercial operation in May 2020.

Technological developments will be a factor in defining the long-term future of nuclear energy and of uranium demand. Advancements in reactor and fuel cycle technology are not only aimed at addressing economic, safety, security, non-proliferation and waste concerns, but also at increasing the efficiency of uranium resource use. The introduction and use of advanced reactor designs and Generation IV designs would also permit the use of other types of nuclear fuels (e.g. fuels based on high assay low-enriched uranium, higher burn-ups, or other fuel compositions such as uranium-238 and thorium) that consume fissile resources more efficiently. In particular, fast neutron reactors are being developed to make more efficient use of the energy contained in uranium. Many national and several major international programmes are working to develop these advanced technologies, for example the Generation IV International Forum and the IAEA International Project on Innovative Nuclear Reactors and Fuel Cycles. In the long term, new reactor designs may bring fundamental changes to the nuclear fuel landscape.

Box 2.2. **Advancing High-Assay Low-Enriched Uranium (HALEU) supply**

High assay low-enriched uranium (HALEU) continues to attract significant attention from global nuclear fuel cycle producers, utilities and governments. Many small modular reactors (SMRs) designers around the world are indeed developing innovative reactor concepts that will require HALEU-based fuel. HALEU is enriched between 5% and 20% and is being proposed for some advanced reactors and SMRs in order to allow for more compact cores, increased fuel cycle lengths, longer life cores and better fuel utilisation overall. The current commercial nuclear power reactors use uranium fuel that is enriched up to 5%, a limit that has become an industry standard and shaped the entire front end of the fuel cycle industry. The transition to a HALEU fuel supply chain would however need a robust market for companies to commit the investments needed and will require fuel cycle infrastructure and regulation updates.

Today, Russia is the only country with an established HALEU commercial supply chain. Several countries are looking to diversify HALEU fuel supply, including the United States. At the end of 2022, the US Department of Energy (DOE) established a HALEU consortium with the aim to pool together entities across all the stages of the nuclear fuel cycle, to partner and support the availability of HALEU for domestic commercial use. In parallel, the DOE secured a contract with the enrichment company Centrus to demonstrate the production of HALEU at the Piketon facility by the end of 2023.

In the short-term, potential recovery methods for HALEU include down-blending of government-owned highly enriched uranium (HEU) stocks. As an example, the United States is working on chemical methods for down-blending HEU to provide small amounts of HALEU to reactor developers in the near term in support of SMR demonstration projects.

Conclusion

As reported in this volume, sufficient uranium resources exist to support continued use of nuclear power and significant growth in nuclear capacity for electricity generation and other uses (e.g. heat, hydrogen production) in the long term. Considering current yearly uranium requirements of about 60 000 tU, identified recoverable resources,[3] including reasonably assured resources and inferred resources, are sufficient for over 130 years. Exploitation of the entire conventional resource[4] base would increase this to around 250 years. Furthermore, uranium exploration and development, motivated by significantly increased demand and market prices, would be required to move these resources into more definitive economic cost categories. Nevertheless, a rapid growth of nuclear power in coming decades would significantly change this picture. Uranium requirements that may arise from emerging applications of nuclear such as SMRs (including electric and potentially non-electric applications) will also need to be considered in these projections when better visibility of these novel applications allows for it.

The uranium resource base described in this report is more than adequate to meet currently projected growth requirements to 2040. As far as the availability of physical resources is concerned, there is no reason to assume major changes in this picture even beyond 2040. However, consumers and producers need to ensure that adequate framework conditions for the exploration, mining, transformation and transport of uranium are in place. This includes pricing mechanisms that allow for sufficient visibility in order to allow for the considerable long-term investments required

Meeting projected low case requirements to 2040 would consume about 20% of the identified recoverable resources available at a cost of <USD 130/kgU and about 15% of identified recoverable resources available at a cost of <USD 260/kgU. For the high case, meeting growth requirements to 2040 would consume about 26% of identified recoverable resources available at a cost of <USD 130/kgU and about 20% of identified recoverable resources available at a cost of <USD 260/kgU. It is worth noting that average uranium market prices beginning in mid-2021 and sustained through the beginning of 2023, were of around USD 130/kg U.

When considering lower cost resources, meeting projected requirements to 2040 would consume about 60% of the identified resources available at a cost of <USD 80/kgU in the low case scenario and about 80% of identified resources in the high demand case.

3. Identified recoverable resources include all cost categories of reasonably assured resources and inferred resources for a total of about 7 917 500 tU (see Table 1.2a).
4. Total conventional resources include all cost categories of reasonably assured, inferred, prognosticated and speculative resources for a total of more than 15 million tonnes (see Tables 1.3a, 1.4a and 1.13). This total does not include secondary sources or unconventional resources, e.g. uranium from phosphate rocks.

Given the limited maturity and geographical coverage of uranium exploration worldwide, there is considerable potential for the discovery of new resources of economic interest. As clearly demonstrated in the last few years, with appropriate market signals, new uranium resources can be readily identified, developed and mined.

As noted in this report, there are also considerable unconventional resources, including phosphate deposits and black schists/shales, which could be used to lengthen the time during which nuclear energy could supply energy demand using current technologies. However, more research and innovation effort and investment would need to be devoted to better define the extent of this potentially significant source of uranium and develop cost-effective extraction techniques.

The development and deployment of advanced reactor and fuel cycle technologies could further significantly add to and stretch global uranium supply in the long term. Moving to advanced technology reactors and recycling fuel would increase the long-term availability of nuclear energy based on the fission of uranium from hundreds to potentially thousands of years. If alternative fuel cycles were developed and successfully deployed, thorium could also be a potential contributor to the nuclear fuel cycle provided existing initial fissile inventories to start such thorium fuel cycles are readily available.

In conclusion, sufficient physical uranium resources exist to meet demand from electricity generation at current and even at increased demand levels until 2040 and beyond. However, for these resources to be fully commercially available, considerable exploration and investment will be required to develop new mining projects in a timely manner and to generate sufficient supply to satisfy demand at reasonable prices.

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Chapter 3. National reports on uranium exploration, resources, production, demand and the environment

Introduction

This chapter presents the national submissions on uranium exploration, resources and production. These reports have been provided by official government organisations (see Appendix 1) responsible for the control of nuclear raw materials in their respective countries, although the details are the responsibility of the individual organisations concerned. In countries where commercial companies are engaged in exploration, mining and production of uranium, the information is first submitted by these companies to the government of the host country and may then be transmitted to the NEA or the IAEA at the discretion of the government concerned. In certain cases, where an official national report was not submitted, and where it was deemed helpful for the reader, the NEA/IAEA has provided additional comments or estimates to complete this report. In such cases, "NEA/IAEA estimates" are clearly indicated.

It should be noted that exploration activities may be currently ongoing in a number of other countries that are not included in this report. In addition, uranium resources may have been identified in some of these countries. It is believed, however, that the total of these resources would not significantly affect the overall conclusions of this report. Nevertheless, the NEA and IAEA encourage the governments of these countries to submit an official response to the questionnaire for the next edition of the Red Book.

Additional information on the world's uranium deposits is available in the IAEA online database *World Distribution of Uranium Deposits – UDEPO* (www-nfcis.iaea.org). UDEPO contains information on location, ranges of uranium tonnage and average grade, geological type, status, operating organisations (in case the deposit is being mined), and other technical and geological details about the deposits.

Thirty-six member countries submitted a response to the questionnaire and the NEA/IAEA drafted 18 country reports. As a result, there are a total of 54 national reports in the following section.

Algeria

Uranium exploration and mine development

Historical review

Over the last forty years, uranium prospecting in Algeria, which began with the launch of a mineral prospecting programme in the Hoggar region, underwent a first stage (1969-1973) marked by a significant investment effort which led to the discovery of the first uranium deposits in the Hoggar Precambrian crystalline basement (Timgaouine-Abankor-Tinef).

These results, obtained through ground radiometric surveys and geological mapping, quickly identified the uranium resource potential of the Hoggar region, which overall has favourable geological and metallogenic characteristics for mineral deposits.

An aeromagnetic-spectrometric survey of the entire country, carried out in 1971, provided the initial incentive and direction for uranium exploration. The processing of the data collected from this survey identified potential regions for further uranium prospecting, including the Eglab, Ouggarta, and Tin Seririne sedimentary basins (Southern Tassili where the Tahaggart deposit was discovered), as well as individual areas in Tamart-n-Iblis and Timouzeline.

While these developments were taking place, uranium prospecting entered a new phase (1973-1981) primarily aimed and focused on the assessment of uranium reserves and the development of previously discovered deposits.

Despite a pronounced slowdown in prospecting activities in the phase that followed (1984-1997), work undertaken in the immediate vicinity of previously discovered deposits and in other promising areas revealed indications of uranium mineralisation and radiometric anomalies in the Amel and Tesnou zones located to the northwest and north respectively of the Timgaouine region.

Surveys conducted in the Tin Seririne Basin (Tassili South Hoggar), provided a basis on which to undertake geologic mapping and revealed the distribution of uranium-bearing minerals in Palaeozoic sedimentary formations.

Recent and ongoing uranium exploration and mine development activities

In 2017 and 2018, the Agency of the Geological Service of Algeria in collaboration with the United States Geological Survey carried out preliminary prospecting work for undiscovered mineral resources (diamond, Au, PGE-Cr, Cu-Ni-PGE-Cr and Mo-Cu) in the Eglabs region, including uranium resources related to granites, calcretes, alkaline rocks and carbonatites.

No uranium prospecting or mine development work was carried out between January 2019 and January 2021. All prospecting programmes were placed on hold, largely due to the COVID-19 pandemic.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

There are two geological types of reasonably assured resources in Algeria: upper Proterozoic vein deposits in the western Hoggar, and a deposit linked to the Precambrian basement and its Palaeozoic sedimentary unconformity in the central Hoggar. The first type includes vein deposits linked to faults crossing the Pan-African batholith in the Timgaouine region, represented by the Timgaouine, Abankor and Tinef deposits in the south-western Ahaggar.

The second type is unconformity-related, represented by the Tahaggart deposit. It is associated with a weathering profile (regolith) developed at the interface between the Precambrian basement and the Palaeozoic cover, and to conglomerates at the base of the Palaeozoic sedimentary sequence in the Tin Seririne Basin (south-east of Hoggar). It is worth noting that the uranium mineralisation discovered in the Ait Oklan-El Bema (north Hoggar) region has not been assessed in terms of uranium resources.

Undiscovered conventional resources (prognosticated and speculative resources)

Algeria does not report any resources in any category other than reasonably assured resources.

Uranium production

Historical review

Algeria does not produce uranium.

Regulatory regime

Mining activities related to raw materials for nuclear energy, and environmental protection aspects to be taken into account for such activities are governed, among others, by:

- Law No. 03-10 of 19 July 2003 on the protection of the environment for sustainable development;
- Law No. 14-05 of 24 February 2014 relating to mining activities;
- Law No. 19-05 of 17 July 2019 on nuclear activities.

Algeria decided to regulate activities related to the research, production and peaceful use of nuclear energy with the adoption of Law No. 19-05 of 17 July 2019 on nuclear activities.

The law sets objectives such as the protection of human health, the environment and future generations against potentially harmful effects related to the use of ionising radiation, while respecting the principles of radiological protection and nuclear safety and security, in compliance with Algeria's commitments under international treaties and conventions. It applies to activities related to nuclear materials and ionising radiation sources, nuclear and radiological installations, radioactive waste, and uranium and thorium ores.

The measures to be put in place by operators, importers, transporters, and holders of radioactive materials to achieve these objectives, including exposure limits, accident prevention measures, or systems to control access to facilities or to combat illicit trafficking in nuclear materials, will be set by regulation.

In application of this law, the National Authority for Nuclear Safety and Security was created under the supervision of the Prime Minister by executive decree (No 21-148 of 20 April 2021). This independent administrative authority, which has legal personality and financial autonomy, is competent, in particular, to draft legislation and regulations relating to nuclear activities and guides of good practice to ensure the safety and security of operations and ensure their application. Its prerogatives also include the issuance of authorisations and licences, the control of installations, the approval of training programmes, the approval and management of emergency plans, and co-operation with international and regional organisations.

Pending the establishment of the authority, the Atomic Energy Commission (COMENA) exercises its prerogatives.

National policies related to uranium

From a mining perspective, in a world market dominated in the short- and medium-term by a small number of producers, it is currently not economically feasible to exploit uranium resources in Algeria.

Algeria's uranium resources can only be exploited in a sustainable manner within the framework of an integrated development of the nuclear sector and its main applications. The latter include, in particular, nuclear power generation and seawater desalination plants, together with applications in medicine, agriculture, water resources and industry.

With regard to the current situation in the global energy market, Algeria is working towards the integrated development of the uranium sector, ranging from exploration to production and encompassing research and development, training, and long-term nuclear power generation prospects.

Gaining control over the uranium production cycle and its applications would require the acquisition of technical expertise, which can only be achieved through ambitious research, development and training programmes. Through its nuclear research centres, Algeria currently has the appropriate tools to undertake work in the future, either alone or through bilateral or multilateral co-operation on various research, development and training programmes.

It is in a spirit of openness and transparency that Algeria applied itself to the task of putting in place the most favourable and appropriate institutional and regulatory framework with which to pursue the energy development of the country, including a Mining Act, Environmental Protection Act, an Oil and Gas Act and recently a civil nuclear activities Act. The latter establishes the regulatory framework for mining activities relating to radioactive minerals, from exploration to mine rehabilitation, including the management of radioactive mining waste.

To improve the mining sector and boost research, exploration and exploitation, the government amended Law 01-10 (of 3 July 2001) by promulgating Law 14-05 on 24 February 2014. This mining law aims to create better conditions for the revival of the sector through adequate funding for research and exploration of new economically viable mining deposits, including uranium.

Uranium stocks

None.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unspecified	0	0	0	26 000
Total	0	0	0	26 000

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unspecified	0	0	0	26 000
Total	0	0	0	26 000

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity				2 000
Granite-related				24 000
Total				26 000

Installed nuclear generating capacity to 2040

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
0	0	0	0	NA	NA	NA	NA	NA	NA	NA	NA

Argentina

Uranium exploration and mine development

Historical review

Uranium exploration activities in Argentina were launched in 1951-1952 by the National Atomic Energy Commission (CNEA), leading to the discovery of the Papagayos, Huemul, Don Otto and Los Berthos uranium deposits. During the late 1950s and the early 1960s, airborne surveys also led to the discovery of the Los Adobes sandstone-type deposits in Patagonia.

During the 1960s, the Schlagintweit and La Estela granite-related deposits were discovered and subsequently mined. During the 1970s, follow-up exploration near the previously discovered uranium occurrences in Patagonia led to the discovery of two new sandstone deposits: Cerro Condor and Cerro Solo. At the end of the 1980s, a nationwide exploration programme was undertaken to evaluate geological units with uranium potential.

From 1990 to 1997, exploration was conducted in the vicinity of the Cerro Solo deposit (Chubut Province), where more than 56 000 m were drilled to test the potential of favourable portions of the paleochannel structure. The results included the localisation and partial evaluation of specific mineralised bodies with 4 600 tU of reasonably assured and inferred resources.

These results allowed the CNEA to complete a preliminary economic assessment of the Cerro Solo U-Mo deposit in 1997, including a revised geological model and ore resource estimates, mining and milling methods and costs, cash flow and risk analysis, as well as the exploration and evaluation of the surrounding areas.

As a result of the national government’s policy announced in August 2006 to reactivate the nuclear programme, different areas of uranium interest have been explore and evaluated.

From 2007 to 2016, a total of 45 672 m was drilled (across 380 boreholes) in the main mineralised areas of the Cerro Solo district, while in the Cerro Solo U deposit, a total of 44 246 m was drilled (373 boreholes) to further stratigraphic correlation and metallogenic studies, mineralogical and hydrometallurgical studies, and triaxial strength.

Other areas under study in Chubut Province were the Sierra Cuadrada Uranium district, where at least four uranium mineralised areas were recognised. In this district, a regional geological survey was carried out in an area of 4 000 ha with geological–radiometric data collection and four drill holes accounting for total drilling of 585 m.

Fluvial and lacustrine deposits of Cretaceous age discoveries were made at the Mirasol Chico site, where a drilling programme of 507 m (3 holes) was completed in 2015, and at the El Cruce site, where radiometric prospecting works and 647 m of drilling were undertaken.

In Santa Cruz Province, the main exploration work was focused on shallow low-grade uranium anomalies in six areas defined as a surficial deposit (calcrete type), and in the Laguna Sirven area the focus was on defining the extension and continuity of uranium mineralisation. Mining properties are shared by FOMICRUZ S.E. and the CNEA.

In the Urcal and Urcuschun deposits, located in La Rioja Province, uranium mineralisation is associated with limestone deposits from the Ordovician age to sedimentary sequences from the Carboniferous-Permian age. Exploration activities included re-examination of old mining activities, geological studies, geophysical exploration and the implementation of a drilling programme of 993 m (13 drilled holes) in 2015.

Systematic geochemical studies and geophysical exploration were carried out at the Alipán I site (perigranitic deposit) in the Velasco Range of La Rioja Province. Between 2010 and 2013, 14 drillings were executed for a total of 2 344 m. Over the eastern side of the Velasco Range, a new area of exploration called Lucero has been studied with encouraging results, and three zones with anomalies and evidence of surface uranium minerals were defined.

At the U Mina Franca perigranitic deposit, located in the Fiambalá Range, Catamarca Province, surface systematic radiometric surveys, geological-structural-metallogenic mapping, mineralogical studies and geochemical analyses have been undertaken. In 2017, surface geological reconnaissance activities were completed, which provided the structural geological base map used to plan a drill programme to define mineralisation at depth.

Geophysical techniques were applied to study mineralisation behaviour in detail in the north and central sectors of the Don Otto deposit (Cretaceous-aged sandstone type), Salta Province. Other activities conducted in the district included geomorphological studies and identification of the geological setting. These works were complemented with a drilling programme totalling 1 734 m (8 holes).

Evidence of uranium mineralisation found in oil wells and, to a lesser extent, known from surface data, have been under analysis in two exploration areas near Catriel town, Río Negro Province. Mineralisation is related to sandstone deposits within the Neuquén Basin. Geophysical exploration was undertaken during 2015 and 2016, complemented with geochemical exploration, geological radiometric reconnaissance and a drilling programme of 1 910 m distributed across 10 boreholes.

Some semi-regional geological recognition activities, including geochemical surveys and geophysical studies, were conducted in an exploration area in Gobernador Ayala, La Pampa Province, and a drilling programme was planned.

In the early 2000s, six private uranium exploration companies began work in Argentina as noted by the *Cámara Argentina de Empresas de Uranio* (CADEU – Argentine Chamber of Uranium Companies): U3O8 Corp. (Meseta Exploraciones S.A. - MEXSA; Calypso Uranium Corp. merged with U3O8 Corp.); Sophia Energy S.A.; Blue Sky Uranium Corp. (Minera Cielo Azul S.A.); Cauldron Minerals Ltd; Gaia Energy Argentina S.A. and UrAmerica Ltd. Of these private companies, U3O8 Corp., Sophia Energy S.A., UrAmerica Ltd and Blue Sky Uranium Corp. continue with their work in Argentina.

The Laguna Salada U deposit (Chubut Province) held by MEXSA, a subsidiary of U3O8 Corp., is a surficial uranium-vanadium deposit and includes the Guanaco and Lago Seco areas with 82% and 12% of the resources, respectively. Mineralisation occurs within 3 m of the surface in soft, unconsolidated gravel. Indicated and inferred in situ resources have been evaluated at 2 420 tU and 1 460 tU, respectively, while vanadium identified resources have been assessed at 21 330 tV. The NI 43-101 report, including exploration results, resource evaluation and the preliminary economic assessment, was issued in 2014. Since then, however, the project has been on hold.

Sophia Energy S.A. carried out the exploration of its calcrete-type vanadium-uranium deposit at the Laguna Sirven site in Santa Cruz Province. Geochemical and biogeochemical surveys and hyperspectral and thermal remote sensing studies were performed in order to spectrally characterise and determine mineralised areas of interest. Trenching and sampling was also carried out.

UrAmerica Ltd undertook an intensive underground exploration programme supported by drilling 250 holes, for a total of approximately 24 000 m, on neighbouring areas of the Cerro Solo ore deposit, in Chubut Province. They report 7 350 tU as inferred in situ resources for the Meseta-Central project. As reported by UrAmerica, about 75% of the uranium resources evaluated are in confined aquifers. Therefore, further geological and hydrological studies will be needed to determine if it is suitable for in situ leach mining. The NI 43-101 report included exploration results and an inferred resource assessment and was issued in 2013. In the same year the project was put in care and maintenance.

Blue Sky Uranium Corp has been actively exploring its Amarillo Grande Project in central Río Negro Province since 2006. Defined mineralisation at Amarillo Grande is found in three target areas (Ivana, Anit, and Santa Barbara) along a 145 km trend. Mineralisation at all three areas occurs at or very near surface in unconsolidated to weakly-cemented host rocks. Surface exploration, ground geophysics, pit sampling and more than 9 000 m of reverse circulation drilling were completed at the project since the beginning of the revitalised work programme in 2016.

Recent and ongoing uranium exploration and mine development activities

As of 2021, the CNEA owns 50 exploration licences in Argentina, considering requested and conceded exploration permit areas (22), statements of discovery (18), and ore deposits (10). They are located within the provinces of Salta, Catamarca, La Rioja, San Juan, Mendoza, La Pampa, Río Negro, Chubut and Santa Cruz.

From 2017 to 2019, exploration activities carried out by the government have slowed down and no drilling has been carried out. The main areas that have been targeted by the CNEA for uranium exploration belong to Cañadon Asfalto Basin (Chubut Province), Neuquén Basin (Río Negro and La Pampa Provinces), Velasco Range (La Rioja Province), Fiambalá Range (Catamarca Province) and Salta Group Basin (Salta Province). In general, the activities have been focused on some field work for geological and radiometric reviews, geophysical surveys, sampling for geochemical analysis and environmental studies.

Of those uranium deposits managed by the CNEA, the most relevant in the assessment/exploration stage is Cerro Solo, which belongs to the homonymous district and is located in Chubut Province. Identified uranium resources of the Cerro Solo deposit total 9 230 tU. To define the hydrometallurgical extraction line of uranium and molybdenum minerals, laboratory-scale sample testing has been completed, but further up-scale testing was postponed. Since 2018, only environmental monitoring has been carried out.

From 2012 to 2019, one of the main activities at the Cerro Solo ore deposit was related to environmental baseline surveying in compliance with provincial regulations. In this regard, hydrological, palaeontological, socio-economic, air quality, flora and fauna, pedological and archaeological studies have been completed, while radiometric/radiological and natural acidic drainage surveys are being developed.

In the framework of an IAEA Coordinated Research Project on “Geochemical and Mineralogical Characterisation of Uranium and Thorium Deposits”, the interpretation of new studies on uranium mineralisation from several uranium sites of interest has improved the metallogenetic understanding of the granite-related deposits and the exploration guidelines.

Due to the COVID-19 pandemic, during 2020 and the first half of 2021, cabinet uranium exploration activities were carried out, consisting of: data collection, processing, and interpretation; writing of technical reports; dissemination, training and teaching activities. Limited laboratory activities were carried out, which included preparation, studies and analysis of geological samples. At the same time, maintenance and servicing tasks of facilities, vehicles and technical equipment were fulfilled, as well as the administrative, legal, and environmental commitments corresponding to the various projects and sites. Field tasks were very limited and reduced to two geological commissions carried out in the Northwest of the country.

Government exploration activities were expected to intensify in the second half of 2021, which included a programme of 1 200 metre drillings (6 drilled holes) in the Neuquén Basin, but the task was postponed until 2022.

Sophia Energy S.A., UrAmerica Ltd, Blue Sky Uranium Corp., U3O8 Corp. and Consolidated Uranium Inc. reported exploration-related activities during the 2017-2021 period. Sophia Energy S.A. continued exploration of its mining properties at the Laguna Sirven deposit in Santa Cruz Province. Activities include processing satellite imagery, geological mapping, ground and airborne radiometric surveys, and geochemical and geobotanical sampling and analyses, a portion of which was carried out in co-operation with the University of Surrey (United Kingdom). In 2018, a radiometric airborne survey of the entire project (600 km^2) was carried out under contract by the National Atomic Energy Commission. All these exploration efforts brought encouraging results. In December 2019, Sophia Energy S.A. received approval from the province of Santa Cruz Mining Authorities to perform an intensive two-year advanced exploration programme focused on resource assessment, but the COVID-19 pandemic caused exploration activities to be put on hold since early 2021.

In 2020, the memorandum of understanding signed in 2018 among UrAmerica Ltd, Uranium One Group from Russia, UrAmerica Argentina and the Government of Argentina, expired. The main purpose of that MOU was to promote co-operation and the joint development of uranium exploration and production focused on ISL, with planned investment amounting to USD 250 million. UrAmerica Ltd plans to set up a subsidiary company based in the United States, which among other goals, would provide uranium exploration investments for its Argentinian uranium projects.

In 2019, Blue Sky Uranium Corp. announced the first preliminary economic assessment for the Ivana deposit (Amarillo Grande project), as well as an updated resource estimate. The inferred in situ resource estimate includes 8 730 tU at 0.031% U and 2 920 tV at 0.011% V. Exploration in 2019 continued to focus on expanding the mineralisation proximal to the Ivana deposit. The first half of the year included additional pit and auger sampling, with a 6 km-long induced polarisation ("IP") geophysical survey and up to 4 500 m of RC drilling planned for the second half of the year. The drilling programme was launched in Q1 2020 but immediately halted due to the COVID-19 pandemic, then resumed in Q1 2021.

In June 2021, U3O8 Corp. announced that International Consolidated Uranium Inc. had been chosen to exercise its option to purchase the Laguna Salada project (Chubut Province) from U3O8 Corp. The terms of the option agreement were outlined in U3O8 Corp.'s press release dated 14 December 2020. In December 2021, International Consolidated Uranium closed its option to acquire the Laguna Salada uranium and vanadium project. This project has been in care and maintenance since 2014, but it is expected that exploration activities will be resumed in the short term.

The information about private exploration expenditures must be taken as only partially complete since the industry is not required to report these expenditures to the government.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

No new reasonably assured and inferred resources have been assessed since the last Red Book edition (2020). Changes observed in figures are due to recalculation to convert in situ into recoverable resources and re-assignment of mining and processing methods taking into consideration available NI 43-101 reports and CNEA internal documents.

Identified recoverable uranium resources (RAR+IR) in Argentina

(as of 1 January 2021)

Deposit (ownership)	Province	Type	RAR tU ≤ USD 130/kgU	IR tU ≤ USD 130/kgU
Sierra Pintada (CNEA)	Mendoza	Volcanic-related	3 900	6 110
Cerro Solo (CNEA)	Chubut	Sandstone	4 420	3 760 (4 810)*
Don Otto (CNEA)	Salta	Sandstone	180	250
Laguna Colorada (CNEA)	Chubut	Volcanic-related	100	60
Laguna Salada (Consolidated Uranium Inc.)	Chubut	Surficial	1 860	1 120
Meseta Central (UrAmerica Ltd)	Chubut	Sandstone	-	5 290
Ivana/Amarillo Grande (Blue Sky U Corp.)	Río Negro	Sandstone (surficial)	-	7 200
Subtotal			10 460 tU	23 790 tU (24 840 tU)*
Total RAR + IR			34 250 tU (35 300 tU)*	

* tU for production cost category of <260 USD/kgU.

As of 1 January 2021, the total identified recoverable resources of Argentina are 34 250 tU at the cost category <130 USD/kgU and belong to seven projects whose main characteristics are mentioned in the appropriate table. It can be highlighted that if the highest production cost category of <260 USD/kgU is considered, there is no substantial variation and total recoverable identified resources amount to 35 300 tU.

Undiscovered conventional resources (prognosticated and speculative resources)

The 13 800 tU prognosticated resources reported in the Red Book 2020 corresponded to five sandstone-type deposits in the Cerro Solo and Sierra Cuadrada uranium districts of Chubut Province (Cerro Solo, El Ganso, Puesto Alvear, El Molino, Sierra Cuadrada Norte and Arroyo Perdido).

As a result of recent interpretation of direct and indirect data, an additional 6 900 tU of prognosticated resources have been evaluated at the Catriel (6 000 tU; sandstone type; Río Negro Province), El Gallo (600 tU; intrusive type; La Rioja Province) and Laguna Sirven (300 tU; surficial type; Santa Cruz Province) deposits. Therefore, total prognosticated in situ resources account for 20 700 tU in the <USD 260/kgU cost category.

To assess the uranium favourability and estimate the potential resources by the application of quantitative McCammon and Deposit Size Frequency (DSF) methods, also used in the US National Uranium Resource Evaluation (NURE) programme, the country was divided into 61 investigation units (IU). These units, which cover 1 450 000 km^2, were delineated on the basis of the geotectonic setting as well as petrological, mineralogical and geochemical characteristics. Speculative uranium in situ resources amount to 79 500 tU according to the resource assessment that has been completed in 5 IUs considered as the units with high uranium potential (i.e. Salta Group Basin, Pampean Ranges, Paganzo Basin, San Rafael Basin and Chubut Group Basin). Sandstone, volcanic-related and granite-related uranium deposit types have been taken into consideration in this approach.

In addition, qualitative methodologies based on spatial modelling and mineral system concepts have been applied to determine uranium exploration targets. The geological units under study are: the Salta Group Basin (sandstone type; Salta province), Pipanaco Salt Flats/Aimogasta Basin (surficial type; Catamarca and La Rioja Provinces), Paganzo Basin (sandstone type; Catamarca and La Rioja Provinces), Western Precordillera and Western Flank of the Pie de Palo Range (sandstone and surficial types; San Juan Province), Ambargasta Salt Flats (surficial type; Santiago del Estero Province), Sumampa Ranges (granite-related type; Santiago del Estero Province), Deseado Massif and related areas (sandstone and surficial types; Santa Cruz Province). Other prospective studies have been conducted, notably related to uranium from phosphates (unconventional resources). In the framework of an IAEA Coordinated Research Project, preliminary studies are underway for the assessment of the uranium potential of phosphate rocks and testing uranium extraction from low-grade phosphate ores. The research project involves studies in three sedimentary basins (Ordovician North-Western Basin, Upper Jurassic – Lower Cretaceous Neuquén Basin, and Paleocene – Miocene Patagonia Basin), where low-grade phosphate mineralisation and uranium anomalies (up to 135 ppm U) have been detected.

Uranium production

Historical review

Argentina produced uranium from the mid-1950s until 1999 with a total of seven commercial-scale production centres and a pilot plant that operated between 1953 and 1970. The closure of one of the last of these facilities in 1995 (Los Colorados) resulted in a change in the ownership structure of uranium production in Argentina, and since 1996 the uranium mining industry has been wholly owned by the CNEA. The last facility that remained operative at that time, San Rafael, was placed on standby in 1997. No uranium has been produced since then, neither privately nor by state. Between the mid-1950s and 1997, cumulative uranium production totalled 2 582 tU.

Status of production facilities, production capability, recent and ongoing activities and other issues

Production projects

Argentina produced about 120 tU/year for about 20 years to provide raw material to fuel its nuclear power plants Atucha I and Embalse, with ore from different sites distributed throughout the national territory. In the late 1990s, the decline in the international price of uranium made domestic production no longer competitive and the decision was taken to shut down the remaining production plants and import uranium. However, changes in recent years have caused the CNEA to review its plans and consider reopening production facilities. These changes are the uncertainties in future external supply and the increase in domestic uranium requirements upon the full capacity operation of the Atucha II reactor, which was reached in 2015. In addition, Embalse was out of the generation system for three years for successful refurbishment to extend its operational life by 30 years and increase its power by an additional 35 MWe. With an installed nuclear capacity of 1.79 GWe, natural uranium requirements are about 220 tU per year. The potential addition of one new PWR-1150 and the development of the CAREM-25 prototype and CAREM-120 commercial reactors will further increase domestic uranium requirements, which could reach approximately 480 tU/year by 2030.

The San Rafael Mining-Milling Complex (CMFSR) Remediation and Reactivation Project

Once the CNEA evaluated the possibility of reopening the production facilities of the San Rafael mining-milling complex (Sierra Pintada mine), an environmental impact assessment (EIA-2004, according to provincial Act 5961) was presented to the authorities in the province of Mendoza and to the Nuclear Regulatory Authority. This study evaluated the potential impacts of uranium concentrate and dioxide production and the treatment of the former wastes simultaneously.

This EIA concluded that former operations had not affected the quality of underground and surface waters in the area, or any other environmental component in the surrounding area. Provincial authorities nonetheless rejected the reopening proposal, arguing that the CNEA must first remediate the open-pit water and the milling wastes stored in drums before restarting production. In response, the CNEA prepared and submitted a new EIA (2006) addressing only the treatment of wastes in temporary storage and pit water. This proposal received technical approval, but not final approval because it lacked the required statutory public hearing. A further complication that increased the difficulty of reopening the plant was the approval of Mendoza Provincial Act 7722 (2007), which prohibits the use of sulphuric acid, among other chemicals, in mining activities.

Currently, the CNEA is constructing evaporation ponds and defining the basic engineering for the simultaneous treatment of open-pit water and milling wastes stored at the San Rafael complex. To date, three effluent evaporation ponds have been finished and one more is under construction. In 2018, the update of the EIA 2006 (EIA, 2013) presented to the provincial control authorities reached a favourable technical opinion and a mandatory public hearing by law was held in 2019 with positive outcomes. Therefore, the provincial authorities granted the environmental impact statement through Resolution N° 259/19.

The CNEA secured sufficient funds for the rehabilitation works of former uranium production facilities from the Bank for Investment Projects in the Ministry of Economy. Having an approved budget means that more time and resources can be devoted to addressing the remediation and rehabilitation works. These activities involve the removal of obsolete facilities, construction of effluent ponds, purchase of equipment and facilities, and other associated activities.

Before restarting uranium production in San Rafael, it is necessary to obtain both provincial approval and agreement to amend the provincial law that prevents the use of sulphuric acid, among other chemicals. Technical feasibility has been partially demonstrated by the fact that this deposit was previously in operation, using the acid heap-leach processing method. Other alternatives have been considered for possible future production, including the use of alkaline leaching, bioleaching and vat leaching. Also, given the possibility of reopening the mining-milling complex, all available data have been processed to redefine the geological model and formulate more suitable mining and processing designs.

The Cerro Solo Project

The CNEA continues developing feasibility studies for the proposed mining of the Cerro Solo deposit (Chubut Province) and several laboratory-scale tests have been carried out to determine the most economically competitive milling process. Since the deposit contains molybdenum in addition to uranium, identifying an appropriate and feasible process is not trivial. Molybdenum could be a valuable by-product, but its presence in the leachate could complicate the exchange resins, so another process, like liquid-liquid extraction, may be used. For this reason, all preliminary investigations have been critical steps in developing a profitable production plan. Recently, the conceptual engineering has been defined.

In the mining sector, a conceptual study was advanced and improved using specific software for geological modelling. A pre-technical economic feasibility study was in development, beginning with prior validation of all information (tonnages, grade, geotechnical, geostructural and hydrogeological) and some surface works.

Currently, the project is in standby status awaiting a governmental decision to continue it, taking into consideration the basic engineering studies of both the mining operation and the processing plant.

Besides technical considerations, a Chubut provincial law 5001/03 that prevents open-pit mining remains in effect and mining projects need to wait for the Chubut provincial territory zoning provisions of the aforementioned law, as well as the introduction of a regulatory framework for mining in this jurisdiction.

Ownership structure of the uranium industry

In Argentina, the uranium industry is owned by the government. Private sector participation exists only in the exploration phase, although legislation provides for the participation of both state and private sectors in uranium exploration and production activities.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #21
Name of production centre	San Rafael Mining-Milling Complex	Cerro Solo Deposit
Production centre classification	Prospective (reopening)	Prospective
Date of first production	NA	NA
Source of ore:		
Deposit name(s)	Sierra Pintada	Cerro Solo
Deposit type(s)	Volcanic-related (synsedimentary)	Sandstone (paleochannel)
Recoverable resources (tU)	6 000	NA
Grade (% U)	0.107	NA
Mining operation:		
Type (OP/UG/ISL)	OP	OP
Size (tonnes ore/day)	550	NA
Average mining recovery (%)	90	NA
Processing plant:		
Acid/alkaline	Acid	Acid
Type (IX/SX)	IX	SX
Average process recovery (%)	78	NA
Nominal production capacity (tU/year)	150	200
Plans for expansion	Yes	NA
Other remarks	Production started in 1976 and ceased in 1997. Remediation activities are underway.	Preliminary stage

Employment in the uranium industry

In connection with the uranium production industry, currently most of the employees are working on development, maintenance and remediation of the San Rafael mining-milling complex.

Future production centres

The development of a new production centre in Chubut Province near the Cerro Solo deposit is the most suitable option for future production. However, the project is on hold and feasibility studies have not yet been carried out.

Production and/or use of mixed oxide fuels

Argentina neither produces nor uses MOX fuel in its nuclear power plants.

Production and/or use of re-enriched tails

In Argentina there is no production or use of re-enriched tails.

Environmental activities and socio-cultural issues

Environmental impact assessments

In Argentina, production permits are subject to both national and provincial legislation. Currently, environmental studies are being undertaken on three major uranium production projects.

The San Rafael Mining-Milling Complex Remediation Project (Mendoza Province)

As stated in the 2018 edition of the Red Book, an update of the 2006 EIA (MGIA-2013) had been presented to the authorities of the Mendoza Province. This study addressed only the treatment of solid wastes (currently in temporary storage) and open-pit mine water. The proposal received technical approval (2013 EIA), which was endorsed after the implementation of the statutory public hearing in 2019. In the meantime, the CNEA has continued to evaluate technical options to minimise environmental impacts and established additional security measures:

- Effluent pond "DN 8-9"

An evaporation pond (5 hectares) with a double lined waterproof high-density polyethylene (HDPE) geo-membrane and a leakage detection system has been built, and hydraulic tests have been successfully accomplished. It is currently being used to manage open-pit water.

- Effluent pond "DN 5"

This precipitation facility is designed to treat open-pit water. This pond will have a total operational capacity of approximately 12 000 m^3 and will have security drainage systems and double waterproofing HDPE geo-membrane to control potential leaks. Its purpose is to provide the necessary conditions (residence time) to generate As and Ra precipitates before they are fed into the effluent pond "DN 8-9" for final disposal. The civil engineering has been approved by the local authorities, with ground stabilisation and slope recontouring completed. Currently, the drainage system pipes and geo-membrane are being installed.

- Other remediation activities

Other activities related to waste management are being undertaken, such as cisterns, waterproofing, designing wastewater treatment systems, repairing facilities and installing pipes to pump effluents between the quarries and the processing and treatment facilities.

Cerro Solo ore deposit (Chubut Province)

As requested by the provincial authorities, the CNEA is developing environmental baseline studies through contracts with universities and institutes, and parts of the studies (archaeological, palaeontological and socio-economic impacts) have already been presented to provincial authorities. In addition, the CNEA continues with communication activities, offering information on mining practices to residents located near the proposed mining projects and areas of exploration.

The Los Gigantes former Mining-Milling Complex Remediation Project (Córdoba Province)

In November 2018, the detailed engineering of the environmental restitution project of the site was presented to provincial authorities and the CNEA is awaiting a response before conducting a public hearing and developing an environmental impact statement.

Monitoring

The San Rafael Mining-Milling Complex Remediation Project (Mendoza Province)

The CNEA currently has an intense monitoring programme, which includes:

- Surface water: surface water and run-off, both upstream and downstream of the facilities, is being sampled systematically to follow the evolution of possible pollutant concentrations (U, As, Ra, among others) inside and outside the CNEA's influence area.
- Groundwater: groundwater within a redesigned well network inside the complex is being sampled systematically.
- Air pollution: particulate matter and radon emissions are periodically sampled in key locations of the complex.
- Open-pit water: open-pit water is being sampled systematically in every pit.
- Sediments: sediments are being sampled systematically in the complex.

Cerro Solo deposit (Chubut Province)

The sampling work includes analysis of water samples from exploration wells, water samples from domestic wells (owned by inhabitants of the area), surface run-off and sediment from streams and springs in the watershed (analysing for U, Ra, As, F, among others). Analysis of air quality includes particulate matter and radon emission measurements.

Effluent management

The San Rafael Mining-Milling Complex Remediation Project (Mendoza Province)

The construction of the "DN 8-9" evaporation pond and the "DN 5" facility for treating open-pit water aims to reduce pollutants to meet provincial water quality standards. Moreover, the design and implementation of a local wastewater treatment system is under study.

Site rehabilitation

The San Rafael Mining-Milling Complex Remediation Project (Mendoza Province)

In general, the CNEA is submitting technical proposals to rehabilitate those areas of the complex that will not be used for uranium production in the future. Topics include rehabilitation of the former tailings dump, open-pits and waste rock management, among others.

Uranium Mining Environmental Restoration Programme

The CNEA is undertaking the Uranium Mining Environmental Restoration Programme (PRAMU). The aim of this programme is to restore the environment as much as possible in every area where uranium mining and milling activities have taken place.

At the Malargüe site (Mendoza Province), the environmental restoration work was completed in June 2017, together with the construction of a recreation space for the community. From that date, a post-closure environmental and radiological monitoring programme was initiated.

The Córdoba and Los Gigantes sites (Córdoba Province) have advanced detailed engineering projects underway. The sites being studied are Huemul (Mendoza Province), Pichiñán (Chubut Province), Tonco (Salta Province), La Estela (San Luis Province), and Los Colorados (La Rioja Province), where environmental baseline studies are being developed. All these sites are the subject of periodic radiological and environmental monitoring. PRAMU seeks to improve the conditions of the tailing deposits and mines to ensure the long-term protection of people and the environment.

The CNEA is required to comply with all legislation that is in force and is under the control of various national, provincial, and local state institutions.

Regulatory activities

Argentina's provinces have legislation limiting certain aspects of mining activities (e.g. use of certain substances, open-pit mining). The local regulations co-exist with national legislation related to mining activities and environmental protection.

National regulations

- Law No. 25 675: "General Environmental Law" establishes minimum standards for achieving sustainable management of the environment, the preservation and protection of biodiversity and the implementation of sustainable development.
- Law No. 1 919: "National Mining Code", which in Title Eleventh (Articles 205 to 212) refers to nuclear minerals (U and Th).
- Law No. 24 585: Requirement to submit an environmental impact assessment (EIA) prior to each stage of development of a mining project. It sets the maximum acceptable limits of various effluent parameters in water, air and soil.

Mendoza provincial regulations

- Law No. 3 790, created the Mining General Direction with specific functions related to the administration, control and promotion of the mining industry in all its phases throughout the province.
- Law No. 7 722 prohibits the use of chemicals such as cyanide, mercury, sulphuric acid, and other toxic substances typically used in metalliferous mining, including prospecting, exploration, exploitation and industrialisation of metal ores obtained by any extraction method in the province.
- Resolution No. 778/96 of the General Department of Irrigation (DGI) regulates all activities that potentially affect surface water and groundwater quality in the province.

Chubut provincial regulations

- Law XVII-No. 68 prohibits open-pit metal mining in the province, as well as the use of cyanide in mining production processes. It also specifies the need for zoning in the province for the exploitation of mineral resources with an approved production model required for each case.

Uranium requirements

The uranium requirements listed below correspond to an estimate made in the Strategic Nuclear Energy Planning 2010-2030 and the reactivation of the Argentine Nuclear Energy Plan launched in 2006. As of the end of 2020, the nuclear plan's status is as follows:

- finishing construction and commissioning Atucha II (achieved);
- extending the licence of Embalse (achieved);
- extending the licence of Atucha I (committed);
- construction of the 4th and 5th nuclear power plants (although only construction of one is currently planned);
- development and construction of a small modular nuclear power reactor (CAREM; in progress);
- reactivation of uranium enrichment (in progress);
- reactivation of uranium mining industry (in stand by status).

The most important update in Argentina's nuclear production was the start-up of Atucha II (745 MWe), reaching first criticality at the end of 2014 and obtaining its commercial operating licence in 2016.

Between 2016 and 2018, Embalse was out of the electricity generation system for refurbishment tasks designed to extend its operating time frame by 30 years, which also increased its output by an additional 35 MWe. In January 2019, the refurbished unit successfully reached criticality and in August of the same year obtained a commercial operation licence for its second life cycle.

During 2024, Atucha I will be inoperative as it undergoes facility refurbishment to extend operation until 2046.

Also proposed is the expansion of the nuclear energy network, which would be covered by the construction of a fourth nuclear power plant consisting of a PWR-type reactor (1 150 MWe by 2030).

In addition, the CNEA is carrying out the construction of the CAREM (27 MWe), a small modular reactor prototype expected to come into operation by 2025. Planning is underway to build another larger unit, CAREM-120 (120 MWe), which is expected to begin operating by 2030.

A pilot plant for uranium enrichment located in the Pilcaniyeu Technological Complex (Bariloche) was operated in the 1980s and early 1990s before deactivation in 1995. A restart project was launched in 2006 and operations resumed in March 2014, enabling Argentina to produce enriched uranium by gaseous diffusion technology. The plant has a capacity of 20 000 SWU/year and in 2015 enriched about 600 kg of UF_6. The CNEA is currently engaged in the development of other enrichment technologies, such as ultra-centrifuges and lasers.

Supply and procurement strategy

In 1992, due to low prices in international markets, uranium concentrates began to be imported from South Africa, eventually leading to the closure of local production in 1997. Since then, there has been no production of uranium in Argentina and uranium requirements for operating nuclear power plants have been met with raw material imports from abroad (i.e. Uzbekistan, Czech Republic, Kazakhstan and Canada).

At present, both government and industry are carrying out exploration projects with the intention of restarting domestic uranium production to achieve the goal of self-sufficiency in uranium supply.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The Nuclear Activity Law of 1997 establishes the roles of the CNEA and the Nuclear Regulatory Authority. It also provides for the participation of the public and private sectors in uranium exploration and development activities.

The National Mining Code of 1994 states that nuclear minerals (uranium and thorium) can be explored and exploited by both the national government and the private sector with legal licences issued by a Competent Provincial Authority. The national government has the first option to purchase all uranium and thorium produced in Argentina and the export of nuclear minerals depends upon first guaranteeing domestic supply and control of the destination of any exports. The government also regulates development activities to ensure practices comply with international environmental standards.

Uranium stocks

Nucleoelectrica Argentina S.A., operator of the domestic nuclear power plants, implements the uranium supply policy and is responsible for guaranteeing a uranium fuel stock of at least two years for Argentina's operational nuclear power plants.

The uranium dioxide producing company (Dioxitek S.A.) acquires uranium oxide concentrates, which in recent years have come from Canada and Kazakhstan. On average, the country imports approximately 220 tU annually.

In addition, the fuel fabrication company (Conuar S.A.) every year imports a few tonnes of low-enriched uranium (LEU), which is required for manufacturing slightly enriched uranium (SEU: 0.85% U-235) fuel for Atucha II and low-enriched uranium (LEU: 1.9/3.2% U-235) fuel for the CAREM SMR prototype.

Uranium prices

Since 1997 uranium needs have been entirely met with purchases on the spot market through international tenders, without subscribing to medium- or long-term supply contracts.

In recent years, the average prices paid by the country have ranged from USD 125/kgU to USD 150/kgU, including transportation fares, taxes, and insurance premiums.

Uranium exploration and development expenditures and drilling effort – domestic

(In Argentine pesos [ARS])

	2018	2019	2020	2021 (expected)
Private* exploration expenditures	39 000 000	32 300 000	48 800 000	287 000 000
Government exploration expenditures	26 900 000	31 800 000	27 380 000	62 990 000
Private* development expenditures	0	0	0	0
Government development expenditures	0	0	0	0
Total expenditures	65 900 000	64 100 000	76 180 000	349 990 000
Private* exploration drilling (m)	2 373	654	385	4 115
Private* exploration holes drilled	236	88	8	80
Private* exploration trenches (metres)	60	0	0	100
Private* tranches (number)	39	0	0	20
Government exploration drilling (metres)	0	0	0	0
Government exploration holes drilled	0	0	0	0
Government exploration trenches (m)	0	0	0	0
Government trenches (number)	0	0	0	0
Private* development drilling (m)	0	0	0	0
Private* development holes drilled	0	0	0	0
Government development drilling (m)	0	0	0	0
Government development holes drilled	0	0	0	0
Subtotal exploration drilling (m)	2 373	654	385	4 115
Subtotal exploration holes drilled	236	88	8	80
Subtotal development drilling (m)	0	0	0	0
Subtotal development holes drilled	0	0	0	0
Total drilling (m)	2 373	654	385	4 115
Total number of holes drilled	236	88	8	80

* Expenditures made by private companies. Government expenditures refer to those corresponding to majority government funding.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	180	180	72
Open-pit mining (OP)*	0	6 990	10 280	10 280*	70-76.7
Total	0	6 990	10 460	10 460	

* 82% of the total has an overall recovery factor of 72% and 18% of the total has an overall recovery factor of 76.7%.

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	1 860	1 860	1 860	76.7
Heap leaching* from UG	0	0	180	180	72
Heap leaching* from OP	0	5 130	8 420	8 420	72
Total		6 990	10 460	10 460	

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	0	2 890	4 600	4 600	72
Volcanic-related	0	2 240	4 000	4 000	72
Surficial	0	1 860	1 860	1 860	76.7
Total		6 990	10 460	10 460	

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	2 430	12 310	18 250	19 300*	72-76.7-82.5
Underground mining (UG)	0	0	250	250	72
Unspecified	0	0	5 290	5 290	72
Total	2 430	12 310	23 790	24 840	

* 57% of the total with an overall recovery factor of 72%, 37% of the total with a recovery factor of 82.5%, and 6% of the total with a recovery factor of 76.7%.

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	2 430	12 310	18 250	19 300**	72-76.7-82.5
Heap leaching* from UG	0	0	250	250	72
Unspecified	0	0	5 290	5 290	72
Total	2 430	12 310	23 790	24 840	

* A subset of open-pit and underground mining, since it is used in conjunction with them.

** 57% of the total with an overall recovery factor of 72%, 37% of the total with a recovery factor of 82.5%, and 6% of the total with a recovery factor of 76.7%.

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	1 950	9 390	16 500	17 550*	72-82.5
Volcanic-related	480	1 800	6 170	6 170	72
Surficial	0	1 120	1 120	1 120	76.7
Total	2 430	12 310	23 790	24 840	

* 59% of the total has a recovery factor of 72% and 41% of the total with a recovery factor of 82.5%.

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	20 100	20 700

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	79 500	0

Historical uranium production by production method

(tonnes U in concentrate)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining[1]	1 859	0	0	1 859	0
Underground mining[1]	723	0	0	723	0
Total	2 582	0	0	2 582	0

1. Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrate)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	753	0	0	753	0
Heap leaching	1 829	0	0	1 829	0
Total	2 582	0	0	2 582	0

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Volcanic-related	1 600	0	0	1 600	0
Sandstone	729	0	0	729	0
Granite-related	253	0	0	253	0
Total	2 582	0	0	2 582	0

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres	54	55	51	52(*)
Employment directly related to uranium production	0	0	0	0

(*) San Rafael Uranium Mining-Milling Complex ceased production in 1997. Only remediation activities are underway.

Mid-term production projection

(tonnes U/year)

2021	2022	2025	2030	2035	2040
0	0	0	0	NA	NA

Mid-term production capability

(tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	0	0	0	0	0	0
2035				**2040**			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA

Net nuclear electricity generation

	2019	2020
Nuclear electricity generated (TWh net)	7.20	10.00

Installed nuclear generating capacity to 2040

(MWe gross capacity)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
1 790	1 790	1 822	1 822	3 092	3 092	4 722	4 842	4 722	5 322

Annual reactor-related uranium requirements to 2040

(tonnes U)*

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
150.2	218.5	224.5	224.5	480.6	480.6	868.7	912.7	868.7	2 030.5

* First core loads for planned new reactors are included in the U requirements data. There are no plans to build an inventory (stockpile) of U.

Armenia

Uranium exploration

Historical review

On 23 April 2007, the Director-General of Rosatom (a state corporation of Russia) and the Armenian Minister of Ecology Protection signed a protocol on conducting uranium exploration work in Armenia.

Based on this protocol, an Armenian-Russian joint venture, CJ-SC Armenian-Russian Mining Company (ARMC), was established in April 2008 for the purpose of geological exploration, mining and processing of uranium. The founders of ARMC are the Armenian government and Atomredmetzoloto of Russia.

Within this framework, the collection and analysis of archival material relevant to uranium mining was completed, and a document, "Geologic Exploration Activity for 2009-2010", specifically regarding uranium ore exploration in Armenia, was published and approved.

In the spring of 2009, fieldwork related to uranium exploration started in the province of Syunik. Geological prospecting carried out on the first Voghchi zone of the Pkhrut-Lernadzor licenced area in 2011 identified some anomalies. All plans for geologic prospecting in 2011 were fulfilled by January 2012. Exploration of the first Voghchi zone of the Pkhrut deposit led to the identification of a very small occurrence, below 1 000 tU inferred resources (category C2 in Russian classification), and indicated that the deposit is prospective.

In 2013, the Armenian-Russian joint venture activities were suspended due to unfavourable uranium market prices.

Uranium production

Armenia does not produce uranium, so there is no associated infrastructure (legislation, regulatory authority, licencing/authorisation system, inspection, etc.).

According to the Strategic Programme for the Development of the Energy Sector of the Republic of Armenia, uranium mining is not foreseen until 2040. On 14 January 2021, this programme was approved by the government of the Republic of Armenia.

Uranium requirements

There have been no changes to Armenia's nuclear energy programme during the past two years. The country's short-term uranium requirements remain the same and are based on the operation of one VVER-440 unit (Armenian-2). A detailed forecast for uranium requirements was carried out, considering the designed lifetime for this reactor, which has an installed capacity of about 407.5 MWe.

Long-term uranium requirements depend on the country's policy in the nuclear energy sector. The approval of the Strategic Programme for the Development of the Energy Sector until 2040, and the schedule ensuring the implementation of this Strategic Programme, include as priorities the extension of operations of the existing power reactor from 2026 to 2036 and the construction of a new nuclear power plant.

Supply and procurement strategy

Nuclear fuel for the Armenian nuclear power plant is supplied by Russia. Armenia's nuclear fuel requirements have remained unchanged over the past two years. The fuel procurement strategy has also remained unchanged and continues to be based on fuel sourced from Russia. The requirements for the proposed new unit will depend on the reactor type.

In 2007, the Armenian government decided that it would enter an agreement with the governments of Kazakhstan and Russia to establish an international uranium enrichment centre (IUEC) at the Angarsk electrolytic chemical combine in Russia. Armenia completed the legal registration of accession and in 2010 joined the IUEC.

Net nuclear electricity generation

(TWh net)

	2020	2021
Nuclear electricity generation (TWh net)	2.55	2.10

Installed nuclear generating capacity to 2040

(MW(e) net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
381	381	420	420	420	420	420	420	NA	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
64	64	64	64	64	64	64	64	NA	NA

Australia

Uranium exploration

Historical review

Australia has maintained involvement in the uranium industry since its inception and remains one of the world's largest producers and exporters of uranium. The majority of Australia's significant uranium deposits were discovered between 1969 and 1980 when exploration expenditures for the commodity were relatively high. Uranium exploration budgets have generally declined since the greenfields discovery of the Kintyre deposit in Western Australia by Conzinc Rio Tinto of Australia (CRA) in 1985. Despite the lack of major recent greenfields discoveries, the resource base has grown through significant brownfields extensions to known resources, and some new occurrences delineated proximally to these with similar geology.

Discovered by Western Mining in 1975 and owned and operated by BHP since 2005, the Olympic Dam mine in South Australia is the world's largest single uranium resource. Production has been continuous since 1988. Australia's uranium has usually been produced from a small number of mines (often only three), though production has shifted localities over time. Mining has occurred at Mary Kathleen and Westmoreland in Queensland; Radium Hill, Mount Painter, Honeymoon, Four Mile and Beverley in South Australia; along with Ranger, Narbalek and Rum Jungle in the Northern Territory.

Most of Australia's uranium resources occur in two main types of deposits: breccia complex deposits, such as Olympic Dam, or unconformity-related deposits, such as Ranger or Kintyre. Other categories include sandstone uranium deposits, such as Honeymoon; surficial (calcrete) deposits such as Yeelirrie or Centipede; and metasomatite, metamorphic, volcanic or intrusive deposits. Australia has no significant deposits of the quartz-pebble conglomerate-type, vein-type and collapse breccia-pipe type.

Australia currently has two operating mines that produce uranium, Olympic Dam and Four Mile, both in South Australia.

Recent and ongoing uranium exploration and mine development activities

Mineral exploration in Australia is undertaken exclusively by commercial entities. However, quality geoscientific databases and information systems are maintained and made available by the Federal Government and relevant state or territory governments, augmenting Australia's favourable geological settings.

Exploration expenditure for uranium decreased in 2020 to AUD 6.7 million from AUD 10.2 million in 2019 and AUD 12.3 million in 2018.

Western Australia

- Mulga Rock

The sandstone-type Mulga Rock resource is wholly owned by Vimy Resources Ltd. It is located 240 kilometres east of Kalgoorlie in Western Australia and consists of four deposits, Ambassador, Emperor, Princess and Shogun. The project involves shallow open-pit mining of four polymetallic deposits with commercial grades of uranium situated in sandstone-hosted carbonaceous material. It has a 15-year mine life and is anticipated to produce 1 346 tU annually. In January 2018, Vimy Resources released a definitive feasibility study for the Mulga Rock project and in September 2021 the Western Australian Department of Mines, Industry Regulation and Safety approved the Mulga Rock mining proposal and associated mine closure plan.

- Yeelirrie

The surficial calcrete-hosted Yeelirrie uranium deposit is wholly owned by Cameco Australia Pty Ltd and is located about 420 km north of Kalgoorlie and 70 km south-west of Wiluna in Western Australia. It is one of the world's largest surficial uranium deposits and is therefore suited to open-pit mining with minimal drilling or blasting required. Cameco acquired the Yeelirrie project from BHP in 2012.

The Yeelirrie Uranium Project received environmental approval from the Western Australia Government in January 2017 and the Commonwealth Government in April 2019.

Future development of the Yeelirrie Uranium Project will depend on better market conditions. It is estimated that average production from the Yeelirrie project would be nearly 3 300 tU per annum over 19 years, utilising open-pit mining and alkaline leach technology.

- Kintyre

The unconformity-related Kintyre uranium deposit is wholly owned by Cameco Australia Pty Ltd, which in 2018 acquired the 30% interest that was held by Mitsubishi Development Pty Ltd. Kintyre is located in the East Pilbara region of Western Australia, approximately 260 km northeast of Newman at the western edge of the Great Sandy Desert. Although there is no outcrop, the Kintyre resource is suited to open-pit mining with the uppermost parts of the resource 50 m below surface.

Cameco Australia secured environmental approval for the Kintyre project in 2015 from the Commonwealth and Western Australian governments. Future development of the Kintyre Uranium Project will depend on better market conditions. Production from the Kintyre project is estimated at around 2 290 tU per annum, with an estimated mine life of 15 years.

- Wiluna Uranium Project

Toro Energy Ltd is the single owner of the Wiluna Uranium Project, which is a surficial calcrete-hosted regional resource located 30 km from the town of Wiluna in central Western Australia. Wiluna comprises six deposits: Centipede, Lake Way, Millipede, Lake Maitland, Dawson Hinkler and Nowathanna. The first four deposits collectively make up the Wiluna Uranium Project, while the Dawson Hinkler and Nowathanna deposits are regarded as advanced exploration prospects.

Mining of the Centipede and Lake Way uranium deposits, including the construction of a processing facility at Centipede, received environmental approval from the Western Australian government in 2012 and the Commonwealth Government in 2013. Toro expanded the Wiluna project proposal, which encompasses the Lake Maitland and Millipede resources, and received environmental approval from the Western Australian government in January 2017 and the Commonwealth in July 2017.

Mining at Wiluna is planned as shallow strip excavation to a maximum depth of 15 metres. The project proposes to use alkaline agitated leaching in tanks at elevated temperatures to process the ore. Production is estimated to be approximately 577 tU per annum.

South Australia

South Australia has five approved uranium mines: Olympic Dam, Honeymoon, Beverley, Beverley North and Four Mile. Only Olympic Dam and Four Mile produced uranium as of 2020. Mining at Beverley and Beverley North has ceased and the sites are working towards closure.

- Olympic Dam

BHP Ltd's breccia complex-hosted Olympic Dam is Australia's largest uranium mine, contributing around two-thirds of Australia's uranium production as a by-product to primary copper production. Plans for a large expansion at Olympic Dam have been scaled back, although BHP plans to steadily increase production capacity under its existing approvals, and in 2018, underground operations commenced in the "Southern Mining Area" of the resource. While production is planned to remain stable in the near term, it is anticipated output will increase over time through incremental production efficiency gains and infrastructure investment.

- Four Mile

The Four Mile mine is located approximately 550 km north of Adelaide. It is operated by Quasar Resources Pty Ltd using in situ recovery (ISR) to extract uranium from sandstone deposits. Uranium is extracted at Four Mile West with other ore bodies identified and under continued delineation at Four Mile East, Four Mile North East and Four Mile North. Uranium-bearing resin from Four Mile is pumped to the Beverley processing plant for elution, precipitation and drying as uranium concentrate.

- Honeymoon

Operated by Boss Energy Ltd, the sandstone-type Honeymoon deposit is currently in care and maintenance. However, it remains approved for mining and exploration and metallurgical test work continues. Mineral exploration continued by Boss Energy in the Yarramba and Billeroo palaeochannels with new resources identified at the Gould's Dam and Jason's deposit. The Honeymoon project comprising, Honeymoon, Gould's Dam and Jason's, has identified, recoverable resources of 23 306 tU. Boss Energy released an Enhanced Feasibility Study of the Honeymoon Project in June 2021.

Northern Territory

- Ranger

Uranium production at the Ranger mine ceased on 8 January 2021 after 40 years of operation that totalled approximately 112 000 tU. The Ranger mine, operated by Energy Resources Australia (ERA; majority owner Rio Tinto with 86.3%) is located in the Pine Creek Inlier and is classified as an unconformity-related deposit. In 2012, Pit 3 mining operations ceased, with production from 2013 being maintained through stockpiled ore material. Activities ceased at Ranger Open Pit 1 in 1994, and as a part of the closure, the pit was filled with tailings and waste rock with a laterite clay cap being placed on the pit surface in 2016. Rehabilitation of the mine area is scheduled to be completed by January 2026.

- Queensland

Queensland hosts more than 80 known sites that contain valuable amounts of uranium, mainly in the remote north-western area of the state. In March 2015, the incoming Queensland government announced that it intended to reinstate a ban on uranium mining. The ban had been repealed in 2012 by the previous government following a period of over 30 years during which no uranium mining had been undertaken in the state. Currently, Queensland allows uranium exploration but not mining.

New South Wales

Uranium exploration was prohibited in New South Wales for 26 years until 2012, when the state government overturned the ban. However, while uranium exploration is currently permitted, the ban on uranium mining remains in place.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

On 1 January 2021, Australia's total identified recoverable uranium resources at a cost of <USD 130/kgU amounted to 1 238 741 tU (1 907 495 tU in situ) of reasonably assured conventional resources and 445 356 tU (700 893 tU in situ) of inferred conventional resources.

Estimated mining and processing losses were deducted from commercial uranium resource reports for individual deposits submitted under the Australian Joint Ore Reserves Committee (JORC) Code. For deposits where this information is not available, an overall mining and milling recovery factor was applied as recommended in the 2021 Red Book Questionnaire. Overall recovery factors range from 58% to 95%.

Notable differences between Australia's previous country report (2020) include an overall increase in RAR but decrease in inferred resources. This is principally accounted for by reported resources at Olympic Dam which show a significant increase in RAR but decrease in inferred resources. Additionally, recoverability information was updated for some deposits.

Although there are more than 35 deposits with identified resources recoverable at costs of <USD 130/kgU, the vast majority of Australia's resources are within the following three individual deposits: Olympic Dam in South Australia, Jabiluka in the Alligator Rivers Region of the Northern Territory, and Yeelirrie in Western Australia. At the Olympic Dam mine, uranium is a by-product of copper mining, with gold and silver also recovered.

Undiscovered conventional resources (prognosticated and speculative resources)

Geoscience Australia does not make estimates of Australia's undiscovered uranium resources.

Unconventional resources and other materials

Geoscience Australia does not make estimates of Australia's unconventional uranium resources.

Uranium production

Historical review

The current phase of Australian uranium production commenced in 1976. Exports are approximately 6 600 (tU) per annum (averaged over ten years), or around 12% of the global market. Uranium produced in Australia is exported to countries in North America, Asia and Europe, and is used as fuel in nuclear power stations to generate electricity.

A review of the history of uranium exploration, development and production in Australia is provided in Australia's Uranium Resources, Geology and Development of Deposits, available at: www.ga.gov.au/webtemp/image_cache/GA9508.pdf.

Status of production capability and recent and ongoing activities

As of 1 January 2021, Australia had three operating uranium mines: Ranger (Energy Resources of Australia Ltd) in the Northern Territory, Olympic Dam (BHP Ltd) and Four Mile (Quasar Resources Pty Ltd), both in South Australia. However, production at the Ranger mine ceased on 8 January 2021.

Five uranium projects in Australia are awaiting better market conditions before proceeding with development: Honeymoon (Boss Energy Ltd) in South Australia, Kintyre and Yeelirrie (Cameco Australia Pty Ltd), Wiluna (Toro Energy Ltd), and Mulga Rock (Vimy Resources Ltd), all in Western Australia.

Total uranium mine production for 2020 from the three operating mines, Olympic Dam, Ranger and Four Mile, amounted to 6 195 tU.

Olympic Dam

Olympic Dam's production of payable metal in concentrate for 2020 was 3 062 tU, a decrease of 300 tonnes from 2019. Olympic Dam contains well over one million tonnes of uranium resources, making it the largest single uranium deposit in the world. It is also the only known breccia complex deposit that has significant economic resources of uranium. Olympic Dam produces copper cathode, refined gold and silver bullion, along with uranium oxide. The BHP-owned underground mine utilises long-hole open stoping technology and cemented aggregate fill, with integrated metallurgical processing.

Ranger

Production at the Ranger mine was 1 335 tU in 2020, a decrease of 150 tonnes, or 10%, from the 1 485 tU produced in 2019. All production at the Ranger mine ceased as of 8 January 2021. Energy Resources Australia (ERA) has produced uranium at Ranger since 1981, with more than 132 000 tonnes of uranium oxide concentrate (112 000 tU) produced. Mining at Ranger Pit 3 concluded in December 2012, but stockpiled ore continued to be processed at the main metallurgical plant and the laterite treatment plant until operations ceased.

Ranger 3 Deeps was discovered in 2009 and is estimated to contain over 34 000 tonnes of uranium oxide (28 830 tU). ERA invested around AUD 120 million in an exploration decline, which was commenced in 2012 and completed in 2014, providing access to the resource for further analysis and assessment. In 2015, ERA's majority owner, Rio Tinto, announced that after careful consideration the company did not support further study or the future development of Ranger 3 Deeps due to the economic challenges facing the project.

The Gundjeihmi Aboriginal Corporation advised ERA in 2016 that the Mirarr Traditional Owners do not support the creation of a new Ranger Authority, which would provide the regulatory mechanism to enable mining after 2021. Rehabilitation activities at the Ranger site have commenced and are scheduled to be completed by January 2026.

Beverley

The sandstone-type Beverley resources, located east of the Flinders Ranges in South Australia, began operations in 1990. Production from Beverley, operated by Heathgate Resources Pty Ltd, started in late 2000, making it Australia's first operating ISR mine. The Beverley and Beverley North mines have been in care and maintenance since early 2012 and 2018, respectively, and since late 2020 have moved into mine closure.

Four Mile

The Four Mile resource comprises two significant sandstone uranium deposits, Four Mile East and Four Mile West, operated by Heathgate Resources on behalf of Quasar Resources Pty Ltd. The initial phase of operations consisted of pumping uranium-bearing solutions to the nearby satellite ion-exchange plant at the Pannikan deposit. The resin produced was initially trucked to the Beverley processing plant for elution, but as of October 2019 it is pumped via trunk lines for precipitation and drying of the uranium concentrates.

Honeymoon

Operated by Boss Energy Ltd, which acquired it in 2015 from Uranium One (Rosatom – the Russian state-owned nuclear industry operator), Honeymoon remains in care and maintenance. Uranium One's production from the Honeymoon project ceased in November 2013. However, all government approvals remain in place, and exploration and metallurgical test work continues.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #2	Centre #3	Centre #4
Name of production centre	Olympic Dam	Four Mile (a)	Honeymoon	Mulga Rock
Production centre classification	Existing	Existing	Planned	Planned
Date of first production (year)	1988	2014	2011	Not known
Source of ore				
Deposit name(s) or district name	Olympic Dam	Four Mile	Honeymoon, Gould's Dam Jason's	Princess, Shogun, Ambassador, Emperor
Deposit type(s)	Polymetallic Fe-oxide breccia complex	Sandstone	Sandstone	Sandstone
Recoverable resources (tU)	1 328 837	14 680	23 306	28 836
Grade (% U)	0.048	0.29	0.15	0.08
Mining operation				
Type (OP/UG/ISL)	UG	ISR	ISR	OP
Size (tonnes ore/day)	12	NA	NA	NA
Average mining recovery (%)	85	NA	NA	95
Processing plant				
Acid/alkaline	Acid	Acid	Acid	Acid
Type (IX/SX)	SX	IX	SX & IX	
Size (tonnes ore/day)	12	NA	NA	NA
Average process recovery (%)	68	85	85	87.3
Nominal production capacity (tU/year)	3 250	1 700	769	1 346
Plans for expansion (yes/no)	yes	no	no	no

	Centre #5	Centre #6	Centre #7
Name of production centre	Yeelirrie	Wiluna	Kintyre
Production centre classification	Planned	Planned	Planned
Date of first production (year)	Not known	Not known	Not known
Source of ore			
Deposit name(s) or district name	Yeelirrie	Centipede, Lake Way, Millipede, Lake Maitland	Kintyre
Deposit type(s)	Surficial (Calcrete)	Surficial (Calcrete)	Proterozoic unconformity
Recoverable resources (tU)	39 409	19 344	18 253
Grade (% U)	0.13	0.09	0.53
Mining operation			
Type (OP/UG/ISL)	OP	OP	OP
Size (tonnes ore/day)	NA	NA	NA
Average mining recovery (%)	NA	NA	NA
Processing plant			
Acid/alkaline	Alkaline	Alkaline	Alkaline
Type (IX/SX)	(d)	IX	NA
Size (tonnes ore/day)	NA	NA	1 700
Average process recovery (%)	80	80	80
Nominal production capacity (tU/year)	3 265	577	2 290
Plans for expansion (yes/no)	no	yes	no

(a) The Four Mile resource comprises Four Mile East and Four Mile West. Uranium-bearing resin from Four Mile is pumped to the Beverley processing plant for elution, precipitation and drying as uranium concentrate.

Ownership of uranium production

Australia's uranium mines are owned and operated by a range of domestic and international companies:

- The Olympic Dam mine is fully owned by BHP Ltd, listed on the Australian Stock Exchange (ASX: BHP).
- The Four Mile mine is fully owned by Quasar Resources Pty Ltd, a subsidiary of Heathgate Resources Pty Ltd, which is in turn owned by General Atomics (United States).

Secondary sources of uranium

Australia does not produce or use mixed oxide fuels, re-enriched tails or reprocessed uranium.

Environmental activities and socio-cultural issues

Environmental approvals

Australia's Commonwealth and relevant state or territory legislative framework require proponents of uranium mines to undertake rigorous and comprehensive environmental impact assessment processes that incorporate public comments on the proposal. A Commonwealth assessment is conducted under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). An EPBC Act assessment is usually undertaken bilaterally with relevant state and territory authorities. An assessment is required for modifications to existing projects along with new proposals, ensuring that strict requirements for environmental, heritage and nuclear safeguards are maintained.

Social factors are also considered in the approvals processes. In particular, Aboriginal Land Rights and Native Title legislation ensures that the concerns and cultural needs of Aboriginal people are respected.

Recent environmental assessments include:

- BHP received approval in February 2015 from the Government of South Australia to raise the wall height of Tailings Storage Facility 4, from 30 m to 40 m. Commonwealth approval was not required. Previously, in 2012, BHP obtained approval to develop an open-pit mine. However, BHP has postponed this proposal indefinitely and, in 2016, announced plans to increase production through an underground expansion into the higher-grade Southern Mining Area at Olympic Dam. In late 2019, BHP received approval to construct Tailings Storage Facility 6 (TSF6) and in mid-2021, received approval to commission and operate TSF6. TSF6 replaces TSF4, which has now reached the end of its operational life.
- Cameco Australia's Kintyre project obtained Western Australian state environmental approval in March 2015 and Commonwealth environmental approval in April 2015.
- Vimy Resources's Mulga Rock project obtained Western Australian state environmental approval in December 2016 and Commonwealth environmental approval in March 2017. Most recently, in September 2021, the Western Australian Department of Mines, Industry Regulation and Safety approved the Mulga Rock mining proposal and associated mine closure plan.
- Toro Energy's Wiluna Extension project, encompassing the Lake Maitland and Millipede resources, obtained Western Australian state environmental approval in January 2017 and Commonwealth environmental approval in July 2017.
- Cameco Australia's Yeelirrie Uranium Project obtained Western Australian state environmental approval in January 2017 and Commonwealth environmental approval in April 2019.

Site rehabilitation

The Ranger mine, operated by Energy Resources Australia, ceased uranium production on 8 January 2021. The Ranger project area will now undergo extensive rehabilitation work that is due to be completed by January 2026. Since 2012, ERA has spent in excess of AUD 683 million on rehabilitation and water treatment at Ranger and expects to invest an additional AUD 800 million on rehabilitation by completion. The Ranger mine closure plan was released by ERA in October 2020 with the objective to rehabilitate the disturbed regions of the project area to a condition similar to the environment of the surrounding Kakadu National Park. The closure plan also includes a maintenance and monitoring programme for 25 years after the rehabilitation programme is completed.

Industry/government collaboration activities

The Uranium Council (UC), formerly the Uranium Industry Framework (UIF), was established by the Australian government in 2009 to develop a sustainable Australian uranium mining sector in line with world's best practice in environmental and safety standards. Membership of the UC comprises representatives of federal, state and territory government agencies, industry, and industry associations.

The UC made a submission to the 2015 South Australian Royal Commission into the nuclear fuel cycle. The UC's submission reviewed its (and the UIF's) work undertaken in three key areas: health and safety, regulation and environmental protection, and community engagement. The submission also provided the following publications developed in response to UC (or UIF) initiatives:

- *Safe and Effective Transport of Uranium* (2007);
- *Review of Regulatory Efficiency in Uranium Mining* (2008);
- *Consolidated Indigenous Engagement Factsheets*;
- *Australia's In Situ Recovery Uranium Mining Best Practice Guide: Groundwaters, Residues and Radiation Protection* (2010);
- *Environmental Protection: Development of an Australian Approach for Assessing Effects of Ionising Radiation on Non-Human Species* (2010);
- *Guide to Safe Transport of Uranium Oxide Concentrate* (2012);
- *Uranium Oxide Concentrate (UOC) Transport Strategy* (2014).

Further information on the UC can be found at www.industry.gov.au/about-us/what-we-do/uranium-council.

National Energy Resources Australia (NERA) is one of six growth centres established by the Australian government under the Industry Growth Centres Initiative. Through a national focus, NERA's roles are to grow collaboration and innovation to help the energy resources industry (petroleum, coal, and uranium) manage cost structures and productivity, direct research to industry needs, deliver the future work skills required and promote fit for purpose regulation. To do this, key strategies include:

- supporting collaborative and innovative research;
- building a resilient and agile supply chain through small and medium-sized enterprises and research sector collaboration;
- promoting industry sustainability through developing a greater understanding of social, environmental, economic and operational consequences of industry activity.

To date, NERA has developed a Sector Competitiveness Plan and in association with management consultants, Accenture, undertook the Australian Uranium Industry Competitiveness Assessment. These reports have outlined several challenges facing the Australian uranium industry, but have also identified several opportunities to assist the industry in becoming more globally competitive. Further information on NERA can be found at: www.nera.org.au.

Regulatory activities

Radiological protection matters arising from uranium mining in Australia are principally the responsibility of the states and territories where mining occurs. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is responsible for developing Australia's national radiological protection framework as laid out in the Radiation Protection Series (RPS), which are implemented through jurisdictional legislation and licence conditions.

ARPANSA's RPS includes a pivotal background document, RPS F-1 *Fundamentals for Protection Against Ionising Radiation* (2014), and several codes and guides relating to uranium mining and associated processes:

- *RPS 9 Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005); RPS 15 Safety Guide for the Management of Naturally Occurring Radioactive Material (NORM) (2008);*
- *RPS 16 Safety Guide for the Predisposal Management of Radioactive Waste (2008);*
- *RPS 20 Safety Guide for Classification of Radioactive Waste (2010);*
- *RPS 9.1 Safety Guide for Monitoring, Assessing and Recording Occupational Radiation Doses in Mining and Mineral Processing (2011);*
- *RPS C-2 Code for the Safe Transport of Radioactive Material (2014);*
- *RPS G-1 Guide for Radiation Protection of the Environment (2015);*
- *RPS C-1 Code for Radiation Protection in Planned Exposure Situations (2016)*.

ARPANSA continues to develop frameworks that guide radiological protection best practice and works closely with industry representative bodies through relevant consultative processes. ARPANSA also administers the Australian National Radiation Dose Register (ANRDR) for the storage and maintenance of dose records of workers occupationally exposed to ionising radiation. Since 2013, ANRDR has complete coverage of the uranium mining and milling industry in Australia with all operations submitting relevant dose records.

A Radon Progeny Technical Coordination Group was established with representation from the uranium mining industry, state regulators, and ARPANSA to develop a national approach to radon progeny dose assessment to address proposed changes in international recommendations. This included a programme of measurements in Australian uranium mines. This work has been published as an Advisory Note on the ARPANSA website: *New dose coefficients for radon progeny: Impact on workers and the public*, and is available at: www.arpansa.gov.au/understanding-radiation/sources-radiation/radon/new-dose-coefficients-radon-progeny-impact-workers.

The Australian government released the 2016 edition of the *Leading Practice Sustainable Development Program for the Mining Industry (LPSDP)* of that year. The latest edition consists of a 17-book series with several updated handbooks and two new handbooks – *Community Health and Safety and Energy Management in Mining*. Further information on the Leading Practice handbooks can be found at www.industry.gov.au/data-and-publications/leading-practice-handbooks-for-sustainable-mining.

Uranium requirements

Australia has no commercial nuclear power plants and has very limited domestic uranium requirements. An Open Pool Australian Lightwater (OPAL) research reactor is operated by the Australian Nuclear Science and Technology Organisation (ANSTO) at Lucas Heights south of Sydney, New South Wales. The OPAL reactor was opened in 2007, with the capacity to produce commercial quantities of radioisotopes utilising low-enriched uranium (LEU) fuel.

Uranium policies, uranium stocks and uranium prices

National policies

Australian policy states Australian uranium can only be sold to countries with which Australia has a nuclear co-operation agreement, to ensure that countries are committed to peaceful uses of nuclear energy. They must also have safeguards agreements with the International Atomic Energy Agency (IAEA), including an Additional Protocol. Australia's network of safeguards agreements now totals 43.

The Australian government supports the development of a sustainable Australian uranium mining sector in line with world's best practice environmental and safety standards. Uranium exploration and mining are currently permissible in South Australia, the Northern Territory and Western Australia. New South Wales overturned legislation prohibiting uranium exploration in 2012; however, uranium mining remains prohibited. In March 2015, Queensland stated it planned to reinstate the ban on uranium mining, which had been overturned in October 2012 by the previous state government, but uranium exploration is permitted. Victoria currently prohibits both uranium exploration and mining. In March 2017, the incoming Western Australian government restated its commitment to place a ban on future uranium activities except for mines that had already been approved by the previous government.

Australia currently has no plans to develop a domestic nuclear power industry, but interest at the state level led to the South Australian Nuclear Fuel Cycle Royal Commission in 2015 and, more recently, the New South Wales Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019 and the Victorian Inquiry into Nuclear Energy Prohibition (2019). At the Commonwealth level, the House of Representatives Standing Committee on the Environment and Energy undertook an Inquiry into the Prerequisites for Nuclear Energy in Australia, also in 2019.

Further, Regulation 9 of *Australia's Customs (Prohibited Exports) Regulations 1958*, provides that the export of goods listed in Schedule 7 of the Regulations is prohibited unless permission is obtained from the Commonwealth Minister for Industry, Innovation and Science or an authorised person. Goods listed in Schedule 7 include minerals, ores and concentrates containing more than 500 parts per million of uranium and thorium combined.

Uranium stocks

For reasons of confidentiality, information on producer stocks is not available.

Uranium prices

The average price of uranium exported from Australia in 2020 was USD 30.27/lb U_3O_8 with exports governed by a combination of contract specifications. Average export prices for the last five years are listed in the table below.

Average export prices for Australian uranium oxide 2015-2020

Average export value	2015	2016	2017	2018	2019	2020
AUD/lb U_3O_8	51.31	43.03	35.90	39.58	42.81	43.83
USD/lb U_3O_8	38.61	32.03	27.53	29.60	30.05.	30.27

Uranium exploration and development expenditures and drilling effort – domestic

(AUD millions)

	2018	2019	2020	2021 (expected)
Private* exploration expenditures	12.3	10.2	6.7	9
Government exploration expenditures	0	0	0	0
Private* development expenditures	NA	NA	NA	NA
Government development expenditures	0	0	0	0
Total expenditures	12.3	10.2	6.7	9
Private* exploration drilling and trenches	NA	NA	NA	NA
Government exploration drilling and trenches	0	0	0	0
Private* development drilling	NA	NA	NA	NA
Government development drilling	0	0	0	0
Subtotal exploration drilling (metres)	NA	NA	NA	NA
Subtotal development drilling (metres)	NA	NA	NA	NA
Total drilling (metres)	NA	NA	NA	NA
Total number of holes drilled	NA	NA	NA	NA

* Non-government.

Conventional reasonably assured resources by production method

(recoverable, tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	NA	NA	94 100	101 873
Open-pit mining (OP)	NA	NA	151 868	174 382
In situ recovery (ISR)	NA	NA	30 160	38 742
Co-product and by-product	NA	NA	962 613	1 002 763
Total	NA	NA	1 238 741	1 317 760

Conventional reasonably assured resources by processing method

(recoverable, tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	NA	NA	1 056 713	1 104 636
Conventional from OP	NA	NA	151 868	174 382
In situ recovery (ISR)	NA	NA	30 160	38 742
Total	NA	NA	1 238 741	1 317 760

Conventional reasonably assured resources by deposit type

(recoverable, tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity	NA	NA	108 004	110 843
Sandstone	NA	NA	62 365	72 252
Polymetallic Fe-oxide breccia complex	NA	NA	969 432	1 009 928
Granite-related	NA	NA	322	322
Intrusive	NA	NA	0	13 873
Volcanic-related	NA	NA	2 433	4 826
Metasomatite	NA	NA	29 281	34 593
Surficial	NA	NA	66 904	71 123
Total	NA	NA	1 238 741	1 317 760

Conventional inferred resources by production method

(recoverable, tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	NA	NA	35 632	48 216
Open-pit mining (OP)	NA	NA	30 317	108 812
In situ recovery (ISR)	NA	NA	13 183	49 750
Co-product and by-product	NA	NA	366 224	435 237
Total	NA	NA	445 356	642 015

Conventional inferred resources by processing method

(recoverable, tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	NA	NA	401 856	483 453
Conventional from OP	NA	NA	30 317	108 812
In situ recovery (ISR)	NA	NA	13 183	49 750
Total	NA	NA	445 356	642 015

Conventional inferred resources by deposit type

(recoverable, tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity	NA	NA	37 491	52 424
Sandstone	NA	NA	32 517	86 258
Polymetallic Fe-oxide breccia complex	NA	NA	366 224	435 237
Granite-related	NA	NA	0	28
Intrusive	NA	NA	0	9 824
Volcanic-related	NA	NA	0	1 089
Metasomatite	NA	NA	8 424	11 916
Surficial	NA	NA	700	45 239
Total	NA	NA	445 356	642 015

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
NA	NA	NA

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	NA

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining	129 684	1 485	1 335	132 504	29
Underground mining1	838	0	0	838	0
In situ recovery (ISR)	13 337	1 764	1 798	16 899	1 866
Co-product/by-product	75 169	3 364	3 062	81 595	1 922
Total	219 028	6 613	6 195	231 836	3 817

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	205 691	4 849	4 397	214 937	1 951
In situ recovery (ISR)	13 337	1 764	1 798	16 899	1 866
Total	219 028	6 613	6 195	231 836	3 817

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Proterozoic unconformity	122 270	1 485	1 335	125 090	29
Sandstone	13 337	1 764	1 798	16 899	1 866
Polymetallic Fe-oxide breccia complex	75 169	3 364	3 062	81 595	1 922
Metasomatite	7 531	0	0	7 531	0
Intrusive	721	0	0	721	0
Total	219 028	6 613	6 195	231 836	3 817

Ownership of uranium production in 2020*

Domestic		Foreign		Totals	
private		Government/private			
(tU)	(%)	(tU)	(%)	(tU)	(%)
3 226	52	2 969	48	6 195	100

* These figures are estimated based on public ownership information. For reasons of confidentiality, government vs private ownership information is not available; there is no Australian government production ownership. Estimated by proportioning domestic private ownership and foreign private ownership for each uranium mining company by its production for 2020.

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres	4 559	3 198	3 134	2 738
Employment directly related to uranium production	3 163	2 220	2 175	1 900

Mid-term production projection (tonnes U/year)

(tonnes U/year)

2021	2022	2025	2030	2035	2040
3 817	5 000	5 000	5 400	5 700	4 000

Mid-term production capability (tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	5 000	5 800	NA	NA	5 400	15 000

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	5 700	10 000	NA	NA	4 000	13 000

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrate	Enriched uranium stocks	Depleted uranium stocks	Reprocessed uranium stocks	Total
Government	0	0	0	0	0
Producer	NA	0	0	0	NA
Utility	0	0	0	0	0
Total	NA	0	0	0	NA

Bangladesh

Uranium exploration and mine development

Historical review

The vision of the Bangladesh Atomic Energy Commission (BAEC) is to contribute to the socio-economic development of the country through the peaceful application of nuclear science and technology. To implement that vision, the BAEC initiated an exploration programme for atomic minerals in favourable geological areas in Bangladesh.

Four regions in Bangladesh are considered to be interesting for uranium exploration: the Eastern Mobile Belt, the Stable Platform, the Dauki Fault Belt and the Dinajpur Slope. The north-eastern border of Bangladesh, located near the Meghalaya uranium province of India, is also potentially promising. Targets include sandstone and basement hosted deposits (U, U-Th-REE), as well as placer deposits (Th, U, REE).

The presence of radioactivity in U and Th bearing zircon- and monazite-rich beach and river sand deposits in Bangladesh was reported in the early 1960s. BAEC has been studying placer minerals along the coastal belts of Bangladesh since its independence and a programme of systematic exploration of heavy minerals was initiated in 1968. The entire south-eastern and southern coastal areas along with their offshore islands were explored from 1968 to 1986. From this detailed survey, a total of 1.76 million tonnes of economic heavy minerals were estimated, among which uranium and thorium bearing zircon and monazite were estimated at 1 158 117 tonnes and 17 352 tonnes, respectively. The findings include:

- Testing of bulk sand samples by BAEC indicate that radioactive heavy minerals can be concentrated in specific fractions.
- In separated zircon fractions, uranium and thorium values of up to 140 ppm U (0.014% U), and 526 ppm Th were identified by neutron activation analysis.
- In radioactive sample concentrates, uranium and thorium were measured as high as 1 400 (0.14% U) and 700 ppm, respectively. Values from mineral grain concentrates were recorded as high as 37 600 ppm Th and 5 120 ppm U (0.512% U) using high-resolution gamma-ray spectroscopy.

In 1976, with assistance from the International Atomic Energy Agency and through the United Nations Development Programme, a reconnaissance radiometric survey was conducted through the Exploration of Uranium and Thorium in Bangladesh project. Some of the highlights of the project:

- A regional reconnaissance survey was completed over a 2 000 km^2 area of the greater Chittagong and Chittagong Hill Tracts and Sylhet districts. More than 150 surface radiometric anomalies were identified.
- An aerial survey was completed over the Jaldi anticline, and a detailed survey was completed over a 450 km^2 area including the Sylhet, Jaintia and Harargaj geological structures.
- Radon surveys were carried out in a 35 km^2 area over the Sylhet anticline and the Jaintia Structure.
- About 27 shallow boreholes were drilled in the Sylhet region resulting in the identification of more than 85 anomalies.

- Uranium indicators were identified in the Harargaj anticline, Moulavibazar District, Eastern Mobile Belt. Most of the samples collected from anomalous beds contain uranium and thorium ranging from 10 to 300 ppm (0.001-0.03% U) and 100 to 1 000 ppm, respectively. The highest radiometric counts occurred in the Phooltala Reserve Forest, at 6 000 counts per second (60 times the background counts). Chemical analysis of this sample indicated the presence of 1 020 ppm of total uranium (0.102% U). Uranothorite and thorianite were identified in the rock samples.

The project was suspended in 1985 before the follow-up exploration of prospective areas. BAEC reinitiated its uranium and thorium exploration activity in 1993 through the Exploration and Exploitation of Atomic Minerals: Joypurhat – Sylhet Area in the Dauki Fault project. Project outcomes include:

- In 1995, a radiometric survey was conducted over various locations along the Dauki Fault, Jaintiapur. Radioactivity in some locations was found to be 5-6 times above background levels. Also, radioactive counts were found to be 4 to 6 times the background level in the Jadukata valley and 3.5 times the background level near the Rangpani River, with a maximum of up to 10 times the background level at one location.
- Gamma logging was completed in a 300 m deep drill hole (EDH-52, drilled by the Geological Survey of Bangladesh at Madarpur, Mithapukur, Rangpur). Total gamma count anomalies of 20-25 times the background level were identified at various depths in the crystalline basement rocks. Larger-scale follow-up surveys have not yet been carried out in prospective regions due to limited budgets and technical know-how. However, BAEC continues to conduct small-scale exploration research.

Recent and ongoing uranium exploration activities

From 2018 to 2020, BAEC completed uranium and thorium exploration over a 12 km^2 area in the Jaintiapur and adjacent Sylhet areas of north-east Bangladesh. The exploration was carried out through the Institute of Nuclear Minerals of the Atomic Energy Research Establishment.

- The range of radon concentration was measured as 8 to 4 360 Bq/m^3 with an average of 851 Bq/m^3, with anomalous values of 2 120 to 4 360 Bq/m^3 observed in the Tertiary sediments, and 8 to 584 Bq/m^3 found in the recent alluvial soil.
- Samples were analysed by neutron activation for uranium and thorium, and enrichments were attributed to the presence of monazite and zircon. Uranium values averaged 5 ppm (0.0005% U), with a maximum of 12 ppm (0.0012% U). Thorium averaged 41 ppm, with a maximum of 100 ppm.
- Average background spectrometric sample values were 611, 45, and 83 Bq/kg, for samples 40K, 226Ra and 232Th, respectively. The highest values recorded for 40K were 1 040 Bq/kg, and 86 and 179 Bq/kg, for 226Ra and 232Th, respectively.

Uranium exploration and development expenditures and drilling effort – Government domestic

(BDT)

	2018	2019	2020	2021(expected)
Government exploration expenditures	500 000	500 000	600 000	700 000
Total expenditures	500 000	500 000	600 000	700 000
Total drilling (metres)	NA	NA	NA	NA
Total number of holes drilled	NA	NA	NA	NA

Recent mine development activities

Bangladesh has no current or planned mine development activities.

Uranium resources and production

Bangladesh has no current uranium resources or production.

Uranium requirements

Bangladesh began construction of its first nuclear power reactor (Rooppur 1) in November 2017 with commissioning scheduled in 2023 and commercial production in 2023 or 2024. Construction of the second unit at Rooppur commenced in July 2018, with completion scheduled for 2024 and commercial production in 2024 or 2025. The country has a rapidly increasing power demand and is aiming to reduce its dependence on natural gas. All fuel for Rooppur will be provided by Rosatom and used fuel will be repatriated to Russia.

Bolivia

Uranium exploration and mine development

Historical review

The Bolivian Nuclear Energy Commission (COBOEN) has responsibility for all the activities of research and application of nuclear energy for peaceful purposes in the fields of geology, mining, metallurgy, research, industry, energy, agriculture, medicine, hydrology and others.

On 3 June 1983, COBOEN was restructured and changed its name to The Bolivian Institute of Science and Technology (IBTEN), embracing the activities of research and application of nuclear techniques, planning and supervision of the development of nuclear technology.

Uranium and thorium prospecting and exploration activities are conducted by the Geological Mining Service of Bolivia (SERGEOMIN), with the specific function of evaluating the potential of such resources. In addition, the Uranium Metallurgy project of the Institute of Mining and Metallurgical Research, has the specific function of completing studies on the extraction of uranium concentrates and the optimisation of production costs based on new techniques within the framework of the national nuclear policy.

The main uranium exploration activities occurred in three stages.

First stage

In 1953, at the request of the Bolivian government, the United States Atomic Energy Commission (USAEC) sent a geological reconnaissance mission to the country to investigate the uranium exploration potential. The mission detected heightened radioactivity in some areas of Bolivia (Potosí and Cochabamba Departments) related to old mines where copper, cobalt and nickel minerals were associated with uranium minerals in the Santa Cruz Department. During this campaign, radioactive anomalies were also identified in the eastern highlands of Santa Cruz, as a result of aerial reconnaissance.

From 1954 to 1955, the USAEC and the former National Department of Geology of Bolivia (DENAGEO) carried out a new exploration campaign, which despite many difficulties encountered in the field, yielded interesting results that were reflected in the report by Henderson and others[*]. Among numerous mines investigated in the Cordillera and Altiplano regions, based on the measurements made on mineral samples, the tin porphyry mine Siglo XX (also known as Siglo Veinte, Llallagua, and Catavi), located close to the city of Llallagua in Bustillos province (Potosí), appeared to have good potential for uranium resources. In addition, other uranium indicators were found in the areas of Sorata, in La Paz and Tasna, in Potosí.

Second stage

In 1963, on behalf of the DENAGEO and the United Nations Development Program (UNDP), a Swedish consulting company carried out an aerial prospecting campaign, covering the Cordillera and the Altiplano regions.

* Henderson, J., M. Honea and G. Donoso (1955), “Appraisal of uranium possibilities in Bolivia”, United States Atomic Energy Commission, Unpublished Report 4060.

The reports presented indicated that there were several radioactive anomalies of variable dimensions, detected mainly in “La Meseta de Los Frailes” in an area of around 15 000 km^2. Despite uncertainties, it was concluded that there were enough indicators to guide the future exploration by COBOEN.

COBOEN paid close attention to the western part of the “Los Frailes” volcanic plateau with the central Altiplano-Cordillera boundary. In 1968 the first exploratory work was planned in this volcanic area.

In 1970, the regional prospecting project began in the “Los Frailes” region, covering the adjacent altiplanic portion, located between Salinas, Sevaruyo and Río Mulato. During this campaign, the Cotaje deposit (the only Bolivian deposit at that time) was discovered in July 1970. In addition, regional prospecting work that year was carried out in the areas of Tupiza, Camargo and Uyuni.

After a technical evaluation of the economic possibilities of the uranium deposits, the Homestake Mining Co., in co-ordination with COBOEN, in 1973 recommended that the evaluation of the prospects in the Sevaruyo area and prospecting in the Chacarilla area with ground and aerial methods should continue and that anomalies found in the Tupiza area should be investigated.

In December 1974, COBOEN authorities delivered two kilograms of uranium concentrates (yellowcake), obtained in its laboratories from Cotaje uranium deposit ore (Potosí), to the national government. This work was carried out in co-operation with the Nuclear Operations and Processes Division, and marked a technological milestone in Latin America and for Bolivian nuclear metallurgy in particular.

Third stage

From 1975, prospecting and exploration was consolidated across Bolivia, though the rate of anomaly discovery was reduced. Activities at the Cotaje deposit were maintained to evaluate the feasibility of the metallurgical mining project and to quantify the economic potential of existing resources, using donated UNDP exploration equipment.

In 1977, the first uranium ore concentration pilot plant was inaugurated in Cotaje (the second in Latin America). Its design, installation and start-up were undertaken exclusively by COBOEN personnel.

In order to increase deposit resources, physical exploration of the Cotaje metallurgical mining complex was intensified in 1979 by means of an electrical resistivity geophysical survey. The geological evaluation found that the estimated resource base did not justify construction of an industrial plant for uranium processing. It was instead decided to expand the Cotaje pilot plant to a semi-industrial scale with a declared rated annual production capacity of 4 tonnes of U_3O_8 in the form of commercial concentrates.

In September 1980, the plant was officially inaugurated, but due to a limited budget and lack of prospecting equipment it was not possible to continue with the discovery of additional resources in the country.

Mining exploration work was resumed in 2008 when the Prefecture of the Department of Potosí contracted the services of the National Geological and Technical Mining Survey (SERGEOTECMIN, now SERGEOMIN) to carry out a prospecting and exploration programme in the Cotaje district and adjacent areas.

Results from the Cotaje mine indicated that mineralisation was low grade and not commercially exploitable. In addition, the uranium grade was less than what was estimated by COBOEN in the 1970s.

During the 2009-2010 period, SERGEOTECMIN conducted a radiometric prospecting survey in the sectors previously investigated by COBOEN, defining Tholapalca, Asunción and Coroma Este as the areas of greatest interest due to heightened uranium anomalies.

Between 2009 and 2011, SERGEOTECMIN signed a contract with the Prefecture of Potosí and subsequently with the Departmental Autonomous Government to conduct exploration. In 2011, more detailed geological exploration was carried out, including a diamond drilling programme at the Tholapalca and Coroma Este sites. However, due to lack of funding, project activities were suspended.

Recent and ongoing uranium exploration and mine development activities

There are currently no exploration and mine development activities.

Identified conventional resources (reasonably assured resources and inferred resources)

According to the December 2011 report on this work, there were 1 720 tU of in situ inferred resources related to volcanic type Cotaje deposit.[†]

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining	0	0	0	1 720	NA
Total	0	0	0	1 720	NA

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	1 720	NA
Total	0	0	0	1 720	NA

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Volcanic-related	0	0	0	1 720
Total	0	0	0	1 720

† Servicio Geológico Minero Bolivia (December 2011), “Prospección y exploración geológico-minera en el Distrito Cotaje, Departamento Potosí, Provincia Antonio Quijarro, Cantón Coroma”, SERGEOMIN Unpublished Internal Report.

Botswana*

Uranium exploration and mine development

Historical review

A surge in the uranium price in the 1970s led to exploration activities in Botswana by various foreign and local companies. Large airborne radiometric surveys were followed by ground surveys, soil sampling, trenching and drilling. However, the thick sand cover in many parts of the country hindered exploration activities. Exploration effectively ceased in the early 1980s with the slump in uranium prices. No deposits of economic interest were discovered in this early phase of exploration, but significant mineralisation was identified in the Karoo sandstones and surficial calcretes, particularly in the east-central part of the country.

Rising uranium prices in 2005 renewed interest in uranium exploration by junior Australian companies, and by 2011, there were 168 uranium prospecting licences registered in Botswana.

A-Cap Resources (currently known as A-Cap Energy) has been exploring in Botswana since 2004, following up on mineralisation discovered by Falconbridge in the 1970s in the Serowe area and further discovering significant mineralisation at the Letlhakane project. Intensive drilling resulted in A-Cap reporting Botswana's first JORC compliant uranium resource in 2008 of just over 100 000 tU at an average grade of 129 ppm U (0.0129% U).

At the end of 2012, A-Cap's prospecting licences for uranium covered 5 000 km^2 while Impact Minerals Ltd controlled 26 000 km^2. The two companies drilled a total of 12 462 m in 95 reverse circulation holes during 2011 but no drilling was reported in 2012. Both companies completed regional ground gravity surveys and Impact Minerals Ltd completed a soil geochemical survey over an area of 250 km^2 at the Ikongwe prospect.

Impact Minerals Ltd, another Australian junior company, acquired permits around A-Cap's areas in early 2008. Exploration activities in 2009 began with airborne radiometric surveys, followed by field reconnaissance, mapping and drilling, leading to the discovery of four prospects in Karoo siltstones and sandstones. In addition to sandstone-hosted mineralisation, there were discoveries of uranium-bearing alaskitic rocks, similar to those found at Rössing in Namibia, and mineralisation related to Proterozoic sedimentary and basement rocks with similarities to the unconformity-related deposits in Canada and Australia. Further work is needed to assess the validity of the model and the potential of this unconformity style of mineralisation.

Impact Minerals was exploring some prospective deposits in eastern Botswana, including Lekobolo, with uranium mineralisation down to 45 m. Further south, it had the Shoshong and Ikongwe prospects in calcrete. In May 2013, Impact announced the sale of four prospecting licences to a local company, Sechaba Natural Resources, but this was not completed due to licensing delays, and in 2014 Impact put its uranium exploration on hold and the majority of Impact's prospecting licences within the Botswana uranium project licences were not renewed.

* Report prepared by the NEA/IAEA, based on previous Red Books and A-Cap Energy Ltd reports.

The Letlhakane uranium deposit has been the focus of detailed technical work for A-Cap since 2010, resulting in the February 2013 release of a positive scoping study. A thorough examination of all aspects of the resource has led to a greater understanding of the framework and grade distribution of uranium mineralisation and the use of appropriate mining techniques to maximise the economics of the deposit.

The uranium mineralisation, hosted predominantly in carbonaceous mudstones and siltstones, occurs in relatively thin (0.5-5 m), laterally extensive lenses with lower-grade material separating higher-grade ore horizons. The nature of the ore combined with shallow, flat-lying and soft strata lends itself well to open-pit extraction methods. This information has resulted in a resource determination that is smaller than previously reported, but with higher grades.

A drilling programme was completed in September 2014 focusing on shallow high-grade zones where initial optimisation runs delineated possible early pits. This drilling was designed to test the continuity and mine scale variability of mineralisation in three main project areas (Kraken, Gorgon and Serule West), and to provide data for further resource modelling and mine planning. This drilling yielded excellent results and confirmed the presence and continuity of high-grade mineralisation within these areas.

A drill optimisation study has also been completed. The drill study focused on the Kraken area where infill drilling had previously been completed. Holes were then excluded to make pre-infill drilling grids. These were completed at 400 m spacing and 200 m spacing as well as 100 x 100 m and 50 x 100 m. At the 400 m and 200 m spacing alternate offset grids were also used to evaluate consistency. The results from the Kraken area concluded that the drilling defines the resource at 200 m spacing and only small variations in grade and contained metal occur when the infill drilling is conducted. This gives A-Cap an excellent guide to defining mineralisation for the project as a whole.

An infill drilling programme that was a follow-up to a major reverse circulation and diamond drilling programme, completed in June 2014, was commenced in October 2014 to further define potential early pilot pits. This programme was successfully completed in November. Resource evaluation, using uniform conditioning (UC) and localised uniform conditioning (LUC) techniques, were conducted. In September 2015, A-Cap announced an upgrade of Letlhakane resources utilising the LUC method. The resources for all deposits, in compliance with the JORC 2012 code, are presented in the table below.

Resources reported by A-Cap, compliant with the JORC 2012 code (September 2015)

Cut-off (U ppm)	Total indicated			Total inferred			Total		
	Mt	U (ppm)	Contained U (tU)	Mt	U (ppm)	Contained (tU)	Mt	U (ppm)	Contained U (tU)
85	197.1	167	32 890	625	172	107 740	822.1	171	140 630
170	59.2	274	16 230	209.7	272	57 010	268.9	272	73 240
255	22.2	393	8 730	81.6	378	30 890	103.8	382	39 620

In August 2015, a mining licence application was submitted to the Botswana Department of Mines. The application was based on the results of a technical study and financial modelling, assuming open-pit mining and heap leaching processing, to produce 1 440 tU/yr over a mine life of 18 years. A detailed programme of acid column leaching, solvent extraction and ion exchange was completed. Uranium recoveries varied from 60.5% to 77.7% depending on the mineralisation type.

Recent and ongoing uranium exploration and mine development activities

In 2017, A-Cap completed in-house processing studies with the objective of reducing acid consumption and increasing recovery. Acid soluble uranium analysis was performed on 296 samples. Results showed spatial and mineralogical relationships with high acid consumption in the Kraken and Gorgon South areas, exhibiting an increase in acid consumption with depth. Optimisation studies identified savings of up to 26% of acid consumption.

A-Cap continued to assess the LUC resources in terms of mining optimisation and in 2018-2019 it continued to attend to the requirements of the Letlhakane Uranium Project's mining licence, including meeting reporting requirements, maintenance of the mining licence boundary, radiation inspectorate, compliance and engaging with the community to update them on the project's status. The Department of Mines confirmed that the mining licence and all prospecting licences continue to be in good standing.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

In September 2015, A-Cap Energy upgraded the global JORC Resource of the Letlhakane Uranium Project. Letlhakane hosts a global resource of 822.1 million tonnes at 171 ppm uranium (0.017% U) for an in situ resource totalling 140 630 tU, based on an 85 ppm U cut-off grade. Within this resource, 32 890 tU belong to the RAR category and 107 740 tU to Inferred. Using a total recovery factor of 62% (mining and processing), the total identified recoverable resource amounts to 87 190 tU in the <USD 130/kg U category.

A-Cap Energy has also defined a higher-grade resource of 73 240 tU, based on the 170 ppm U cut-off grade, or 39 620 tU, based on the 255 ppm U cut-off grade.

Undiscovered conventional resources (prognosticated and speculative resources)

The key feature for uranium mineralisation in Botswana is the presence of highly radiogenic granitoid suites, most relating to the Pan-African (~500 Ma) magmatic event, which introduced uranium-rich source material into the upper crust. The uranium mineralisation is highly mobile and, through leaching, uranium-bearing solutions became concentrated in reduced environments in sandstones, mudstones and carbonaceous materials in the overlying lower Karoo system.

Most calcareous sediments in the Gojwane and the Foley area, which lies on the Karoo and the Karoo-aged sediments, are presumed to host widespread and continuous uranium mineralisation. These areas are considered to have the same geology as the Letlhakane area, which hosts one of the biggest undeveloped uranium deposits in Botswana.

Impact Minerals Ltd reports "target conceptual" undiscovered resources of less than 2 000 tU; however, the uncertainty of this term, and the small amount reported, do not warrant inclusion as undiscovered resources at this time. Although undiscovered resources no doubt exist, further work is required to develop the estimates.

Uranium production

From 2013-2015, A-Cap conducted feasibility studies required for the application of a mining licence for the Letlhakane Uranium Project.

Physical test work on expected lithology mixes was done to evaluate productivity and mining costs using surface miners. Metallurgical test work was completed to optimise the process design and provide geotechnical, geochemical, and hydrological data for studies on heaps and waste products. Process test work was based on heap leach processing using acid leaching for the primary oxide and secondary mudstone ore, and alkaline leaching for the secondary calcrete ore. The uranium recoveries varied from 60.5% to 77.7% depending on mineralisation type.

On completion of the feasibility study, a mining licence application was submitted to the Botswana Department of Mines in August 2015. The mining licence was granted by the Minister of Minerals, Energy and Water Resources on 12 September 2016, and is valid for 22 years.

A-Cap Resources anticipated starting production at its uranium mine by 2018, with a production capacity of 1 440 tU/yr, at an average operating cost of USD 34.9/lb U_3O_8 (USD 90.7/kgU) in the first five years and USD 40.70/lb U_3O_8 (USD 105.8/kgU) during the life of the mine.

On 23 April 2019, A-Cap met with the Botswana Department of Mines and submitted a letter requesting an amendment to extend by two years the commencement of the pre-construction and construction period for the Letlhakane Uranium Project. On 20 August 2019, A-Cap received confirmation from the Botswana Minister of Mineral Resources, Green Technology and Energy Security, that the amendment was approved. The amended date for the commencement of the pre-construction and construction period is now 30 October 2021. In September 2021, the Minister extended the start of construction to 30 September 2024, amending a condition of the mining licence.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1
Name of production centre	Letlhakane
Production centre classification	Prospective
Date of first production	NA
Source of ore:	
Deposit name(s)	Gojwane/Serule
Deposit type(s)	Secondary/calcrete
Recoverable resources (tU)	87 180
Grade (% U)	0.017
Mining operation:	
Type (OP/UG/ISR)	OP
Size (Mt ore/year)	24 000
Average mining recovery (%)	90
Processing plant:	
Acid/alkaline	Acid
Type (IX/SX)	Heap leaching
Size (Mt ore/year); for ISR (litre/hour)	
Average process recovery (%)	69
Overall recovery factor (%)	62
Nominal production capacity (tU/year)	1 440

Environmental activities and socio-cultural issues

A-Cap has established a Safety, Health, Radiation, Environment and Community Group aimed at informing, educating and involving local communities with regard to their activities. Meetings are held on a regular basis. The company submitted an environmental and social impact assessment study of the Letlhakane project to the Botswana government in 2011. The scoping study indicates potential for a mine life of more than 20 years, subject to world market prices for uranium.

A detailed water exploration programme by A-Cap has confirmed that a well field located 30 km west of Letlhakane could supply water of sufficient quality and quantity to meet the project's requirements. A-Cap submitted water rights applications which were subsequently granted by Botswana's Water Apportionment Board in 2012.

An environmental and social impact assessment (ESIA) consistent with the Botswana government's requirements was completed in 2014 and submitted in May 2015 to the Department of Environmental Affairs (DEA). Studies determined that with appropriate mitigation all environmental and social aspects during the construction and planned operations could be addressed. The ESIA findings were presented to the Serule and Gojwane Kgoltas, the Mmadindare and Paje subland Boards, and the Tonata council.

Following a comprehensive review by the DEA, A-Cap was advised in March 2016 that it had adequately identified and assessed impacts associated with the project. A four-week public review was completed, following which the environmental and social impact assessment was approved on 13 May 2016.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

National policies regarding uranium exploitation and production are under development and no regulations for uranium mining and milling are currently in place. However, the government is committed to encouraging private investment in exploration and new mine development. The fiscal, legal and policy framework for mineral exploration, mining and mineral processing in Botswana is continuously being reviewed to make it more competitive. Amendments made to the Mines and Minerals Act in 1999 and the Income Tax Act in 2006 streamlined licensing, enhanced security of tenure and reduced royalty payments and tax rates.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	20 390	20 390	62
Total	0	0	20 390	20 390	62

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Heap leaching* from OP	0	0	20 390	20 390	62
Total	0	0	20 390	20 390	62

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	20 390	20 390
Total	0	0	20 390	20 390

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	66 800	66 800	62
Total	0	0	66 800	66 800	62

Inferred conventional resources by processing method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Heap leaching* from OP	0	0	66 800	66 800	62
Total	0	0	66 800	66 800	62

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	66 800	66 800
Total	0	0	66 800	66 800

Brazil

Uranium exploration and mine development

Historical review

The Brazilian National Research Council began systematic prospecting for radioactive minerals in 1952. These efforts led to the discovery of the first uranium occurrences at Poços de Caldas (State of Minas Gerais) and Jacobina (State of Bahia). In 1955, a technical co-operation agreement was signed with the United States to assess the uranium potential of Brazil. After the creation of the National Nuclear Energy Commission (CNEN), a mineral exploration department was organised with the support of the French Alternative Energies and Atomic Energy Commission (CEA) in 1962.

In the 1970s, CNEN exploration for radioactive minerals accelerated with the addition of financial resources. Further incentive for exploration was provided in 1974 when the government opened NUCLEBRAS, an organisation with the exclusive purpose of uranium exploration and production. One of the early achievements of the government organisations was the discovery and development of the Osamu Utsumi deposit on the Poços de Caldas plateau.

In late 1975, Brazil and Germany signed a co-operation agreement for the peaceful use of nuclear energy. It was the beginning of an ambitious nuclear development programme that required NUCLEBRAS to increase its exploration activities. This led to the discovery of eight areas hosting uranium resources, including the Poços de Caldas plateau, Figueira, the Quadrilátero Ferrífero, Amorinópolis, Rio Preto/Campos Belos, Itataia, Lagoa Real and Espinharas (discovered and evaluated by Nuclam, a Brazilian-German joint venture).

As a result of the Brazilian nuclear development programme reorganisation of 1988, Indústrias Nucleares do Brasil S.A. (INB) discontinued uranium exploration activities in 1991. Since then, limited exploration work has been done to further define resources in Lagoa Real province.

Recent and ongoing uranium exploration and mine development activities

During the 2012-2017 period, exploration efforts focused on favourable areas related to albitic metasomatites of LR 09, LR 35 and LR 36 deposits in the north part of the Lagoa Real province. No exploration work was done during the 2018-2020 period.

In late 2020, the INB started the reassessment of resources in several deposits in the provinces of Lagoa Real and Santa Quitéria. Results were expected for the end of 2021.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Brazil’s conventional identified uranium resources are hosted in the following deposits:

- Poços de Caldas (Osamu Utsumi mine) with the orebodies A, B, E and Agostinho (collapse breccia-type);
- Figueira and Amorinópolis (sandstone);
- Itataia, including the adjoining deposits of Alcantil and Serrotes Baixos (phosphate);
- Lagoa Real Province, Espinharas (metasomatic);

- Campos Belos (metamorphite);
- Pitinga (by-product Sb/ Nb; granite-related);
- others including the Quadrilátero Ferrífero with the Gandarela and Serra des Gaivotas deposits (paleo-quartz-pebble conglomerate).

No additional resources were identified during the 2019-2020 period.

Undiscovered conventional resources (prognosticated and speculative resources)

Based on exploration activities in the Rio Cristalino (Proterozoic unconformity) area and additional resources at the Pitinga site (granite-related), in situ prognosticated resources are estimated to amount to 300 000 tU.

Speculative uranium resources amount to some 500 000 tU according to a preliminary resource assessment that has been completed in geological environments with high uranium potential. Different geological types of uranium deposits were included in this estimate.

Uranium production

Historical review

The Poços de Caldas uranium production facility, which started production in 1982 with a design capacity of 425 tU/year, was operated by the state-owned company NUCLEBRAS until 1988. At that time, Brazil's nuclear activities were restructured. NUCLEBRAS was succeeded by the INB and its mineral assets transferred to Urânio do Brasil S.A. With the dissolution of Urânio do Brasil in 1994, ownership of uranium production is 100% controlled by the INB, a state-owned company.

Between 1990 and 1992, the production centre at Poços de Caldas was on standby because of increasing production costs and reduced demand. Production was restarted in late 1993 and continued until October 1995. After two years on standby, the Poços de Caldas production centre was shut down in 1997 and a decommissioning programme started in 1998. This industrial facility was used to produce rare earth compounds from monazite treatment until 2006, but closed the next year for market reasons.

The Caetité unit (Lagoa Real province) is currently the only uranium production facility in operation in Brazil. The open-pit part of the Cachoeira deposit was entirely mined out in 2014.

Status of production facilities, production capability, recent and ongoing activities and other issues

The expansion of Caetité unit (Lagoa Real) to 670 tU/year is progressing and production is expected to restart in 2027. Expansion of the mine includes development of one underground and one open-pit mine.

Both the licensing process for underground mining of the remainder of the Cachoeira deposit and resource reassessments are underway. Production is expected to start in 2027.

Planning for expansion included the evaluation of several scenarios and involves replacement of the current heap leaching (HL) process by conventional agitated leaching. The overall investment in this expansion is estimated to amount to USD 90 million.

Since 2014, the INB has been working on the development of the Engenho deposit, which was initially planned as an additional ore source for increased production at the Caetité plant, but is currently the only ore source for the plant due to the delay in commissioning the Cachoeira underground mine. The unit started operating in a commissioning process in 2019-2020 without significant production. Mine production in 2021 was 30 tU.

Ownership structure of the uranium industry

The Brazilian uranium industry is 100% state-owned through the INB.

Employment in the uranium industry

Employment at existing production centres slightly decreased in 2018 from 2016-2017, with a small increase in 2019-2020 (see table below).

Future production centres

The Santa Quitéria phosphate/uranium project, a partnership between the INB and a Brazilian fertiliser producer, remains under development. In 2012, the project operators applied for a construction licence, but it was denied in 2018. The INB and its partner have developed a new model for the project and a revised licence application was filed in 2020, with a decision expected in 2022. The operation is currently scheduled to begin in 2024.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #2	Centre #3
Name of production centre	Caetité/Cachoeira	Santa Quitéria	Caetité/ Engenho
Production centre classification	Planned	Planned	Existing
Date of first production	2027	2024**	2020
Source of ore:			
Deposit name(s)	Cachoeira	Santa Quitéria	Engenho
Deposit type(s)	Metasomatic	Phosphate	Metasomatic
Recoverable resources (tU)	10 100	50 000**	5 000*
Grade (% U)	0.3	0.08	0.2
Mining operation:			
Type (OP/UG/ISL)	UG	OP	OP
Size (tonnes ore/day)	1 000	13 000**	1 000
Average mining recovery (%)	90	90	90
Processing plant:			
Acid/alkaline	Acid	Acid	Acid
Type (IX/SX)	SX	SX	HL/SX
Size (tonnes ore/day)			
Average process recovery (%)	90	80**	70
Nominal production capacity (tU/year)	340	1 950**	220
Plans for expansion (yes/no)	No	No**	Yes
Other remarks	OP operation from 1999 to 2014	Co-product phosphoric acid	To be sent to Caetité mill

* Expected production at Engenho mine.

** Updated according to current project.

Environmental activities and socio-cultural issues

Licences in Brazil are issued by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) and the CNEN.

The closure of Poços de Caldas in 1997 ended the exploitation of this low-grade ore deposit that produced vast amounts of waste rock. Several studies have been carried out to characterise geochemical and hydrochemical aspects of the waste rock and tailings dam to better establish the impact they may have had on the environment and to develop the necessary mitigation measures. A remediation/restoration plan, considering several alternatives, was submitted to the regulatory body at the end of 2012. Depending on the option adopted, the costs of implementing the remediation/restoration plan could reach USD 300 million. In the meantime, some measures have been taken to reduce environmental impacts, such as uranium recovery from acid drainage (resin), heavy metal precipitation (ozone), and surface drainage optimisation. The INB, regulators and central government are involved in the consolidation of a work plan for the remediation.

The licensing of Santa Quitéria Uranium/Phosphate Project is split into a non-nuclear part, involving milling and phosphate production, and a nuclear part, involving uranium concentrate production. The INB has applied for local construction licences under the guidelines established by the IBAMA and the CNEN.

Regulatory regime

Licences are issued by the IBAMA, according to Brazilian environment law and CNEN regulations.

Government policies and regulations established by the CNEN include basic radiological protection directives (NE-3.01 – *Diretrizes Básicas de Radioproteção*), standards for licensing of uranium mines and mills (NE-1.13 – *Licenciamento de Minas e Usinas de Beneficiamento de Minérios de Urânio ou Tório*) and decommissioning of tailing ponds (NE-1.10 – *Segurança de Sistema de Barragem de Rejeito Contendo Radionuclídeos*), as well as standards for conventional U and Th mining and milling (NORM and TENORM NM 4.01 – *Requisitos de Segurança e Proteção Radiológica para Instalações Mínero-Industriais*). In the absence of specific norms, the recommendations of the International Commission on Radiological Protection and the International Atomic Energy Agency are used.

The CNEN oversees nuclear research and regulation, but due to the potential future growth of the Brazilian nuclear programme, the creation of a separate independent nuclear regulatory agency is under study by the federal government. In this regard, a bill was submitted to the congress in 2021.

Uranium requirements

Brazil's present uranium requirements for the Angra 1 nuclear power plant, a 630 MWe pressurised water reactor (PWR), are about 150 tU/yr. The Angra 2 nuclear power plant, a 1 245 MWe PWR, requires 220 tU/yr. The start-up of the Angra 3 nuclear power plant (a similar design to Angra 2) was scheduled initially for 2016, but construction was stopped in 2015. With the resumption of construction, Angra 3 is scheduled to be operating in 2026. Once in operation, it will add another 220 tU/yr to annual domestic demand.

A new version of the national energy plan, "Plano Nacional de Energia 2050" (PNE 2050), issued in 2020, is a fundamental study of long-term planning for the country's energy sector. It assesses trends in production and use of energy and evaluates alternative strategies for expanding energy supply in the coming decades. The PNE 2050 also establishes guidelines for the role of nuclear power in the national strategy, including post-Fukushima risk perception and increasing costs, mastery of the complete nuclear fuel production cycle, and the possibility of exporting such products, taking into consideration the scale of production and competitiveness. Depending on different scenarios, nuclear generation could reach 10 GW in 2050.

Supply and procurement strategy

All domestic production is designated for domestic requirements. The shortfall between demand and production is met through market purchases. In the 2019-2020 period, the INB acquired a total of 650 tU.

The planned uranium production increases are designed to meet all reactor requirements, including the Angra 3 unit and all units foreseen in the planned long-term expansion of nuclear energy for electricity generation.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The INB, a 100% government-owned company, oversees fuel cycle activities that are conducted under state monopoly. The INB is currently working on increasing uranium concentrate production and towards the full implementation of fuel cycle activities required to meet domestic demand.

Uranium stocks

The Brazilian government does not maintain stocks of uranium concentrate or enriched uranium product.

Uranium exploration and development expenditures and drilling effort – domestic

(in BRL [Brazilian real])

	2018	2019	2020	2021 (expected)
Private* exploration expenditures	0	0	0	0
Government exploration expenditures	0	0	0	0
Total expenditures	0	0	0	0

* Non-government.

Reasonably assured conventional resources by production method*

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	72 900	72 900	72 900	72 900	90 (mine); 90 (process)
Open-pit mining (OP)	9 900	9 900	9 900	9 900	90 (mine); 70-90 (process)
Co-product and by-product	101 500	126 900	126 900	126 900	NA
Total	184 300	209 700	209 700	209 700	

* No changes in resources in the period 2017/18 due to absence of mining activities.

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	72 900	72 900	72 900	72 900	90 (mine); 90 (process)
Conventional from OP	4 900	4 900	4 900	4 900	90 (mine); 90 (process)
Heap leaching* from OP	5 000**	5 000	5 000	5 000	90 (mine); 70 (process)
Unspecified	101 500	126 900	126 900	126 900	NA
Total	184 300	209 700	209 700	209 700	

* A subset of open-pit and underground mining since it is used in conjunction with them.

** Expected to be produced at Engenho mine.

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	25 400	50 800	50 800	50 800
Collapse breccia-type	500	500	500	500
Metasomatic	82 300*	82 300	82 300	82 300
Phosphate	76 100**	76 100	76 100	76 100
Total	184 300	209 700	209 700	209 700

* Associated with the Lagoa Real site. Recovery cost will be further evaluated.

** Associated with the Santa Quitéria site. Operating expenditures for uranium recovery are considered (incremental cost for uranium extraction).

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	3 400	3 400	3 400	90 (mine); 80 (process)
Co-product and by-product	0	44 600	112 300	112 300	NA
Unspecified	0	56 900	56 900	56 900	NA
Total	0	104 900	172 600	172 600	

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	3 400	3 400	3 400	90 (mine); 80 (process)
Unspecified	0	101 500	169 200	169 200	NA
Total	0	104 900	172 600	172 600	

Inferred conventional resources by deposit type
(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	13 000	13 000	13 000
Paleo-quartz-pebble conglomerate	0	15 000	15 000	15 000
Granite-related	0	0	67 700	67 700
Metamorphite	0	1 000	1 000	1 000
Collapse breccia-type	0	26 400	26 400	26 400
Metasomatic	0	5 000	5 000	5 000
Phosphate	0	44 500	44 500	44 500
Total	0	104 900	172 600	172 600

Prognosticated conventional resources
(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
300 000	300 000	300 000

Speculative conventional resources
(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	500 000

Historical uranium production by production method
(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining*	4 216	0	0	4 216	30
Total	4 216	0	0	4 216	30

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method
(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	1 097	0	0	1 097	0
Heap leaching*	3 119	0	0	3 119	30
Total	4 216	0	0	4 216	30

* A subset of open-pit and underground mining since it is used in conjunction with them.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Collapse breccia-type	1 097	0	0	1 097	0
Metasomatic	3 119	0	0	3 119	30
Total	4 216	0	0	4 216	30

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres	500	550	550	550
Employment directly related to uranium production	310	310	350	350

Mid-term production projection (tonnes U/year)

2021	2022	2025	2030	2035	2040
30	220	220	2 170*	2 170*	2 170*

* Excluding Caetité expansion.

Short-term production capability (tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
220	2 170*	220	2 170*	220	2 170*	220	2 170*

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
220	2 170*	220	2 170*	NA	1 950*	NA	1 950*

* Excluding Caetité expansion.

Net nuclear electricity generation

	2019	2020
Nuclear electricity generated (TWh net)	16.13	14.05

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
1 875	1 875	1 875	1 875	1 875	3 120	3 120	NA	3 120	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
400	400	400	400*	400	550	550	NA	550	NA

* First core Angra 3 (400 tU) in 2025 not included.

Bulgaria*

Uranium exploration and mine development

Historical review

The presence of uranium mineralisation in Bulgaria, in the Buhovo ore deposit 25 km from Sofia, has been known since 1920. The first exploration activities were undertaken in 1935. More serious exploration activities using technological research methods and economic calculations were carried out between 1938 and 1939 with the co-operation of German specialists. The first 300 tonnes of uranium ore were mined in 1939.

During 1946-1947, Soviet geologists performed intensive geological investigations of the Buhovo ore deposit. In the spring of 1946, a joint Soviet-Bulgarian enterprise was established, but its activity ceased in 1956. The Rare Metals Bureau of the Council of Ministers was established and existed until 1992, when the government decided to cease all uranium production activities.

A large number of exploration methods were applied: geological, geophysical, technological and combined methods. Aero-gamma-ray-spectrometry, hydro-radio-geochemical and water-helium photography were used for exploration.

In total, 39 ore deposits were discovered, dozens of mines were developed across the country, and two facilities for the processing of uranium ore and production of uranium concentrate (U_3O_8) were built in Buhovo and Eleshnitsa.

Bulgarian uranium deposits are small to medium in size (up to 10 000 tU), with ore grades of about 0.1% U. They have complex morphologies and irregular mineralisation. Deposits exploited via classical mining methods have complex geological structures and are situated mainly in mountain regions (Stara Planina, Rhodope massif, East Sredna Gora). The areas of the ore beds range between 250 m^2 to 20 000 m^2, with an occurrence depth of about 500 m and low metal concentration. Technical mining conditions and geological parameters resulted in a high prime cost and lower efficiency of uranium production.

The main ore deposits for underground mining are: Buhovo near Sofia; Eleshnitsa, Senokos and Simitli in south-west Bulgaria; Vinishte and Smolyanovtsi in north-west Bulgaria; Sliven in central Bulgaria; Smolyan, Dospat and Selishte in the Rhodopa Mountains.

When sediment-hosted mineralisation was found, the acid in situ leaching (ISL) mining method was adopted[1]. It was first used in 1969 and applied mainly (90% of the time) to sandstone-hosted deposits (roll-front) using drilling systems (wellfields) for leaching, and occasionally (10% of the time) to hardrock deposits using underground systems.

Deposits of this type were found first in regions of the Upper Thracian Valley, then also in the Struma river valley and in the Dospat river valley. Uranium-bearing horizons occur at 30 to 250 m below the surface. Their thickness varies from 10-12 m to 60-80 m. Uranium mineralisation is hosted by Pliocene sandstone with a thickness varying from 0.4 m to 7-8 m. Uranium grades are variable, within large limits, but with an average value of 300 ppm U (0.03% U).

* This report is based on the 2007 and 2009 Red Books and a partial Red Book 2022 questionnaire response.

1 International Atomic Energy Agency, (2016), "In Situ Leach Uranium Mining: An Overview of Operations", IAEA Nuclear Energy Series NF-T-1.4 report STI/PUB/1741.

In the case of hardrock deposits, the dimensions of ore bodies vary by height from 50-70 m to 500-600 m and by thickness from 2-4 m to 80-100 m. Uranium grades are between 0.03% U to 0.2-0.3% U.

Recent and ongoing uranium exploration and mine development activities

Uranium exploration and mine development activities were terminated in 1990. No exploration was conducted in recent years and no new exploration is expected to be conducted as of 2021.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 1991, identified conventional resources amounted to 20 565 tU in situ, which at the time were determined to be subeconomic based upon prevailing market conditions and processing technology.

A revised resource estimate was made based on a select subset of deposits using data from a Redki Metali State Company report (a final report coinciding with the termination of uranium, exploration and mining activities in 1990) and from subsequent reports submitted to the Specialised Expert Committee on Reserves and Resources (SEC), within the Ministry of Environment and Waters.

As of 1 January 2009, the remaining identified conventional uranium resources were estimated to be 19 809 tU in situ, of which 11 908 tU were determined to be amenable to underground mining methods, and 7 901 tU amenable to ISL methods.

The 11 908 tU of in situ resources amenable to underground methods are associated with 67 different sites (locations) where *insignificant* quantities of uranium were detected. These deposits and their resources were considered subeconomic with little or no production potential.

The 7 901 tU of in situ resources amenable to ISL mining methods were considered to be potentially economic. During production in 1991, an average recovery factor of 65% was achieved based on ISL operations at 16 sites.

To date, no official estimates of the cost of production have been performed. The stated evaluation of the identified conventional uranium resources is unchanged as of 1 January 2021. No determinations of the identified conventional resources per cost category are available.

Undiscovered conventional resources (prognosticated and speculative resources)

Prognosticated conventional resources are estimated to amount to about 25 000 in situ tU. No classifications of the undiscovered conventional resources per cost category are available.

Unconventional Resources and other materials

No unconventional resources have been identified.

Uranium production

Historical review

Up to 1990, 60 000 tU stocks were assessed and about 16 500 tU were produced. Production grew from 150-200 tU/y in the 1950s to 430 tU in 1975. The adoption of the ISL mining method for uranium production from Upper Thracian uranium deposits raised the production to 660 tU in 1989, when 70% of the uranium was ISL extracted. Ores were processed in the two hydrometallurgical plants. Uranium extraction from ISL sorbent resins and their processing was done at the Zvezda plant near Eleshnitsa. U_3O_8 was produced with 80-82% of concentration (68-70% U).

Status of production facilities, production capability, recent and ongoing activities and other issues

At present no production centres exist that could be operated for uranium extraction. If plans for the renewal of uranium production were considered, independent of who operates these facilities, the entire process would need to be built from the beginning.

At the former uranium ore processing plant Zvezda, an installation for ion-exchange resins is operational. This facility serves for the purification of uranium-contaminated mine waters. It is a small capacity installation of some 742 m^3 of resins per year.

Since 1992 the only activities have been the dismantling of facilities, closing of mining works, re-cultivation of contaminated areas, purification of uranium-contaminated mine waters, and environmental monitoring.

Ownership structure of the uranium industry

All uranium production was carried out by the state.

Employment in the uranium industry

There is currently no uranium production and no exploration or production-related employment.

Environmental activities and socio-cultural issues

Uranium production and processing ceased by Government Decree No 163 of 20 August 1992.

Remediation activities from uranium production and processing include: technical liquidation, technical and biological re-cultivation, purification of uranium-contaminated mine waters, and environmental monitoring of the areas affected by the uranium mining.

Presently the main part of the environment re-cultivation from the uranium mining impact is considered completed.

Uranium requirements

The Bulgarian nuclear power programme was launched in 1974 with the commissioning of the first nuclear power unit of the Kozloduy Nuclear Power Plant. The nuclear facilities are concentrated at the Kozloduy Nuclear Power Plant site, where six units were built (units 5 and 6 are in operation and units 1-4 are in the process of decommissioning). In 2020, nuclear power provided about 40.8% of total electricity production in Bulgaria. With an operable nuclear power capacity of 2 006 MWe (2 VVER V-320 units at Kozloduy), uranium requirements are estimated at 322 tU/year.

The lifetime extension of units 5 and 6 is a top priority. From 2014 to 2018, the Plant Lifetime Extension (PLEX) project was completed. The project results demonstrated the units' technical capabilities for long-term operation – until 2047 for unit 5 and 2051 for unit 6. The Nuclear Regulatory Agency (NRA) Chairman issued operating licences for unit 5 in 2017 and for unit 6 in 2019.

On 22 May 2019, a call for the procedure to select a strategic investor for the Belene Nuclear Power Plant project was published in the Official Journal of the European Union. The call also gave an opportunity to declare interest in acquiring a minority shareholding in the project, and/or for purchasing electricity from the power plant.

By the deadline of 19 August 2019, 13 companies had submitted applications. On 19 December 2019, a shortlist of candidates was published, to whom a call for binding tenders was submitted. The shortlisted companies included China National Nuclear Corporation (CNNC), Atomenergoprom AD as part of Rosatom, Korea Hydro-Nuclear Power, Framatom SAS, France, and General Electric, United States. The procedure envisages that negotiations be held with the companies included in the shortlist to structure the Belene Nuclear Power Plant project. The implementation of the procedure has been delayed due to the COVID-19 pandemic.

By decision of the Council of Ministers, dated April 2012, the construction of new nuclear power capacity at the Kozloduy Nuclear Power Plant was agreed upon in principle. In August 2013, the NRA issued a permit for determining the location of a nuclear power plant (site selection). The following activities have also been implemented: technical-economic analysis for the construction of a new nuclear power unit at the Kozloduy Nuclear Power Plant site; research and determining the location of the preferred site for the construction of new nuclear unit at Kozloduy; and performing an environmental impact assessment (EIA) of the investment proposal for building a new nuclear power unit at the Kozloduy site. In 2016, a procedure was launched to appeal the EIA decision before the Supreme Administrative Court (SAC). In April 2019, the SAC rejected the appeal and the EIA decision was adopted. In the beginning on April 2019, a request for approval of the selected site was submitted. On 21 February 2020, an order to determine the location of the site (site 2) was issued by the Chairman of the NRA.

Supply and procurement strategy

The Kozloduy Nuclear Power Plant fuel cycle does not include the purchase of uranium, its conversion or enrichment, but only the purchase of fuel assemblies from the supplier, their interim storage at the plant site after being removed from reactor cores, spent fuel transport for reprocessing, and further disposal of high-level waste. Those activities are based on an agreement between Bulgaria and Russia, as well as on commercial contracts for the supply of nuclear fuel and reprocessing of spent nuclear fuel.

In accordance with the European Energy Security Strategy, a study was conducted to explore options on diverse enriched uranium supplies for the manufacture of fuel assemblies, as well as for the identification of an alternative supplier of fuel assemblies.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

There have been no changes to the legal basis related to uranium. At present, Bulgaria does not intend to renew uranium mining activities.

Uranium stocks

There have been no changes in the uranium stock levels.

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining*	90	0	0	90	0
Underground mining*	11 985	0	0	11 985	0
In situ leaching	4 272	0	0	4 272	0
Total	16 347	0	0	16 347	0

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	11 526	0	0	11 526	0
In-place leaching*	549	0	0	549	0
In situ leaching	4 272	0	0	4 272	0
Total	16 347	0	0	16 347	0

* Also known as stope leaching or block leaching.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	8 700	0	0	8 700	0
Polymetallic Fe-oxide breccia complex	4 640	0	0	4 640	0
Granite-related	1 497	0	0	1 497	0
Metamorphite	366	0	0	366	0
Volcanic-related	1 144	0	0	1 144	0
Total	16 347	0	0	16 347	0

Net nuclear electricity generation (TWh net)

	2019	2020
Nuclear electricity generated (TWh net)	15.379	15.776

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Canada

Uranium exploration

Historical review

Uranium exploration in Canada began in 1942, with the focus of activity first in the Northwest Territories where pitchblende ore had been mined since the 1930s to extract radium. Exploration soon expanded to other areas of Canada, resulting in the development of mines in northern Saskatchewan and in the Elliot Lake and Bancroft regions of Ontario during the 1950s. In the late 1960s, exploration returned to northern Saskatchewan where large high-grade unconformity deposits were discovered in the Athabasca Basin and later developed (the first was the Rabbit Lake deposit, discovered in 1968, and brought into production in 1975). Saskatchewan is now the sole producer of uranium in Canada.

Recent and ongoing uranium exploration and mine development activities

During 2019 and 2020, exploration efforts continued to focus on areas favourable for the occurrence of deposits associated with the Proterozoic unconformity in the Athabasca Basin of Saskatchewan. Very little exploration activity occurred in other areas of Canada in 2019 and 2020.

Surface drilling, as well as geophysical and geochemical surveys, continued to be the main tools used to identify new uranium occurrences, define extensions of known mineralised zones, and reassess previously discovered deposits.

Exploration activity has led to new uranium discoveries in the Athabasca Basin. Notable recently discovered large high-grade uranium deposits include Phoenix/Gryphon, Triple R, Arrow and Fox Lake.

Domestic uranium exploration expenditures amounted to CAD 162 million in 2019, down 5% from CAD 170 million in 2018. Domestic exploration expenditures decreased further in 2020, to CAD 88 million, primarily due to the COVID-19 pandemic work restrictions. In 2019 and 2020, overall Canadian uranium exploration and development expenditures amounted to CAD 276 million and CAD 193 million, respectively.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2021, Canada's total identified conventional uranium resources recoverable at a cost of <USD 80/kgU amounted to 292 400 tU, an increase of 8.5% from the 2019 estimate of 269 500 tU. Canada's total identified uranium resources recoverable at a cost of <USD 130/kgU were 588 500 tU as of 1 January 2021, an increase of 4.2% compared to the 2019 estimate of 565 000 tU. These increases are primarily due to two unconformity deposits, Phoenix and Heldeth Túé, which are now proposed to be mined using lower cost ISL methods. Canada no longer reports uranium resources in the <USD 40/kgU cost category. Companies that previously reported deposits with resources in the <USD 40/kgU cost category have reassessed these deposits using a cut-off grade that reflects a price of <USD 80/kgU. The <USD 80/kgU category more closely reflects recent uranium prices as well as increased costs of production. Most of Canada's identified uranium resources are re-evaluated annually by the uranium mining companies.

The bulk of Canada's identified conventional uranium resources occur in Proterozoic unconformity-related deposits in the Athabasca Basin of Saskatchewan and the Thelon Basin of Nunavut. These deposits host their mineralisation near the unconformity boundary (below, above and across) in either monometallic or polymetallic mineral assemblages. Pitchblende prevails in the monometallic deposits, whereas uranium-nickel-cobalt assemblages prevail in the polymetallic assemblages. The average grade varies from 1% U to over 15% U. None of the uranium resources referred to or quantified herein are a co-product or by-product output of any other mineral of economic importance. Mining losses (~10%) and ore processing losses (~3%) were used to calculate known conventional resources if not provided by the company.

The percentage of identified conventional uranium resources in existing or committed production centres that are recoverable at <USD 80/kgU, <USD 130/kgU and <USD 260/kgU are 100%, 63.5% and 53.1%, respectively. All the resources in existing or committed production centres are updated annually by the mining companies.

Undiscovered conventional resources (prognosticated and speculated resources)

Prognosticated and speculated resources have not been a part of recent resource assessments; hence there are no changes to report in these categories since 1 January 2001.

Uranium production

Historical review

Canada's uranium industry began in the Northwest Territories with the 1930 discovery of the Port Radium pitchblende deposit. Exploited from 1933 to 1940 for radium, the mine was reopened in 1942 in response to uranium demand for the Manhattan Project. Provincial and Territorial bans on private exploration and development were lifted in 1947 and 1948, and by the late 1950s some 20 uranium production centres had started up in Ontario, Saskatchewan and the Northwest Territories. Production peaked in 1959 at 12 200 tU. No further defence contracts were signed after 1959 and production began to decline. Despite government stockpiling programmes, output fell rapidly to less than 3 000 tU in 1966, by which time only four producers remained. While the first commercial sales to electric utilities were signed in 1966, it was not until the mid-1970s that prices and demand had increased sufficiently to promote expansions in exploration and development activity. By the late 1970s, with the industry firmly re-established, several new facilities were under development in Saskatchewan and Ontario. Annual output grew steadily throughout the 1980s, as Canada's focus on uranium production shifted increasingly to Saskatchewan. The last remaining Ontario uranium mine closed in mid-1996. Uranium production peaked at 14 039 tU in 2016 when the Cigar Lake mine reached full output, but production has declined since 2016 due to the suspension of operations at Rabbit Lake and McArthur River/Key Lake in response to low uranium prices.

Status of production capability and recent and ongoing activities

All active uranium production centres are in northern Saskatchewan and operated by Cameco Corp. (Cameco) and Orano Canada Ltd (Orano). Current Canadian uranium production is well below the full licensed production capacity of the uranium mills. Production in 2020 was 3 878 tU, 44% below 2019 production of 6 944 tU, as operations were suspended for six months due to the COVID-19 pandemic. In 2020, Canadian uranium production was at its lowest level since 1975. The Cigar Lake mine and McClean Lake mill were returned to production in April 2021; however, total output for 2021 (4 692 tU) is still below 2019 production as operations continue to be affected by the COVID-19 pandemic. Operations at the McArthur River mine and Key Lake mill have been suspended since January 2018 in response to low uranium market prices. Cigar Lake is expected to return to full production (6 900 tU) in 2022 and Canadian production is expected to increase further when operations at McArthur River and Key Lake resume.

Cameco is the operator of the McArthur River mine, a Cameco (70%) and Orano (30%) joint venture which was the world's second-largest uranium mine in terms of annual production in 2017 and is the world's largest high-grade uranium deposit. Production was idled indefinitely in January 2018 in response to low uranium demand; however, the mine is expected to restart when markets improve. At the mine, ground freezing is used to reduce water inflow from the overlying rock formation and the high-grade ore (>5% U) is extracted using raise bore mining with concrete used as a backfill. A high-grade ore slurry is produced by underground crushing, grinding and mixing, which is then pumped to the surface and loaded on specially designed containers that are shipped 80 km southward by road to the Key Lake mill. The remaining identified resources for McArthur River mine are currently 154 100 tU with an average grade of 5.5% U.

The Key Lake mill is a Cameco (83%) and Orano (17%) joint venture operated by Cameco. The mill has been in care and maintenance since January 2018 due to low uranium prices. In 2018, 61 tU were recovered from cleaning the mill circuits and a further 6.1 tU was recovered in 2019. There was no production from the Key Lake mill in 2020.

The McClean Lake production centre, operated by Orano, is a joint venture between Orano (77.5%) and Denison Mines Corp. (22.5%). In December 2020, Orano purchased the 7.5% share that was held by Overseas Uranium Resources Development (Canada) Co. Ltd, a subsidiary of Overseas Uranium Resources Development Corporation of Japan. Open-pit mining was completed in 2008 and ore containing 2 500 tU was stockpiled to provide mill feed. Production in 2009 and 2010 amounted to 2 045 tU and was obtained from processing the higher-grade ore from the stockpile. The 500 tU of ore remaining in the stockpile was not economic to process so the mill was placed into care and maintenance in July 2010. Production from the McClean Lake JEB mill resumed in 2014 to process low-grade ore from the stockpile and high-grade ore from the Cigar Lake mine. Production from Cigar Lake ore was 6 938 tU in 2019, but dropped to 3 878 tU in 2020 and then increased 4 692 tU in 2021, due to the idling of operations for 6 months during the COVID-19 pandemic and its lingering effects.

Production from the Rabbit Lake production centre, wholly owned and operated by Cameco, has been idled since mid-2016 due to low uranium prices. Production could resume when uranium prices recover. Exploratory drilling at the Eagle Point mine during the past several years has increased identified resources to 27 000 tU at an average grade of 0.63% U.

Cigar Lake, with identified resources of 111 100 tU at an average grade of 11% U, is the world's third-largest high-grade uranium deposit. The mine began operation in March 2014 and is a Cameco (50.025%), Orano (37.1%), Idemitsu (7.875%) and Tokyo Electric Power Company (5%) joint venture operated by Cameco. Cigar Lake was the world's largest producing uranium mine in 2019; however, production decreased by 44% in 2020 due to the COVID-19 pandemic, although production appears to be recovering in 2021, it is 32% below 2019 production. Ground freezing is used to reduce groundwater inflow and ore is extracted using an innovative jet bore mining method with concrete used as backfill. The high-grade ore slurry is then shipped by road to the McClean Lake (JEB) mill for processing. The McClean Lake mill produced 6 938 tU, 3 878 tU, and 4 692 tU from Cigar Lake ore in 2019, 2020 and 2021 respectively.

Ownership structure of the uranium industry

Cameco Corp. (Cameco) and Orano Canada Ltd. (Orano) are the operators of the current uranium production centres in Canada. Cameco is the owner and operator of the Rabbit Lake production centre, which includes the Eagle Point mine and the Rabbit Lake mill. Cameco is also the operator of the McArthur River mine and the Key Lake mill, which are joint ventures with Orano. Cameco is the majority owner and operator of the Cigar Lake mine, in which Orano, Idemitsu and the Tokyo Electric Power Co. (TEPCO) have minority ownership. Orano is the majority owner and operator of the McClean Lake production centre in which Denison Mines Corp. has minority ownership.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5
Name of production centre	McArthur River /Key Lake	McClean Lake	Rabbit Lake	Cigar Lake	Midwest
Production centre classification	Idled	Existing	Idled	Existing	Planned
Date of first production	1999/1983	1999	1975	2014	NA
Source of ore:					
Deposit name(s)	P2N et al.	JEB, McClean, Sue A-E, Caribou	Eagle Point	Cigar Lake	Midwest
Deposit type(s)	Unconformity	Unconformity	Unconformity	Unconformity	Unconformity
Recoverable resources (tU)	154 100 tU	12 100 tU	27 000 tU	111 100 tU	19 000 tU
Grade (% U)	5.5	1.1	0.63	11.0	1.52
Mining operation:					
Type (OP/UG/ISR)	UG	UG/OP	UG	UG	OP
Size (tonnes ore/day)	~200	NA	NA	~200	NA
Average mining recovery (%)	NA	NA	NA	NA	NA
Processing plant:					
Acid/alkaline	Acid	Acid	Acid	Processed at McClean Lake	To be processed at McClean Lake
Type (IX/SX)	SX	SX	SX		
Size (tonnes ore/day)	864	300	2 880		
Average process recovery (%)	98	97	97		
Nominal production capacity (tU/year)	9 600	9 200	6 500	6 900	2 300
Plans for expansion		Expansion of tailings capacity	Expansion of tailings capacity		

Employment in the uranium industry

Employment in Canada's uranium production industry (including head office employees), totalled 1 844 in 2018, 1 824 in 2019 and 1 934 in 2020. Employment directly related to uranium production, including contract workers, was 831 in 2018, 913 in 2019 and 746 in 2020. The reduced employment at the mine and mill sites in 2020 is primarily the result of only allowing essential staff to work at the sites during the COVID-19 pandemic.

Future production centres

Two uranium mining projects in Saskatchewan that would feed existing mills could enter into production within the next decade should uranium prices increase. Ore from Orano's proposed Midwest mine, which has received environmental approval, would provide additional feed for the McClean Lake mill. Ore from Cameco's proposed Millennium mine would be processed at the Key Lake mill. Cameco has also identified other deposits (Fox Lake, Tamarack) that could feed existing mills.

Several other exploration projects in the Athabasca Basin have recently identified large high-grade uranium deposits that have the potential for development. In the western Athabasca Basin, the Arrow deposit (NexGen Energy Ltd.) is the world's second-largest high-grade uranium deposit (130 000 tU) and a project to develop an underground mine and a mill is currently undergoing an environmental assessment. The nearby Triple R deposit (Fission Uranium Corp.) is a high-grade uranium deposit (52 000 tU) which also has indicated and inferred gold resources totalling

67 000 ounces and has recently undergone a Pre-Feasibility Assessment for the development of an underground mine. In the eastern Athabasca Basin, Denison Mines Corp.'s Phoenix deposit (26 900 tU) is undergoing an environmental assessment process for a proposal to develop an ISL mining operation. The Phoenix deposit is located in permeable sandstone above the unconformity and ground freezing is proposed in the sandstone overlying the deposit to create the confining conditions required for ISL operations. Denison Mines Corp.'s nearby Gryphon deposit (24 000 tU) has the potential to be mined by conventional underground methods. In 2020, Denison conducted a Preliminary Economic Assessment for mining the Heldeth Túé deposit (former name: J-Zone deposit) at Waterbury Lake using ISL methods.

There is also a possibility of mines being developed outside of Saskatchewan; however, uranium prices would have to increase substantially. Orano has proposed developing the Kiggavik and Sissons deposits in Nunavut, should market conditions improve and mining becomes economic.

Secondary sources of uranium

Canada does not use secondary sources of uranium. Canada does not produce or use mixed oxide fuels nor use re-enriched tails.

Environmental activities and socio-cultural issues

Environmental impact assessments

As indicated above, environmental assessments are currently underway for proposals to develop the Arrow deposit in the western Athabasca Basin and the Phoenix deposit in the eastern Athabasca Basin.

Effluent management

Water treatment and minor engineering works continued to be the main activities at the closed Elliot Lake area uranium mine and mill sites in 2019 and 2020. Water quality within the Serpent River Watershed has improved since the closure and decommissioning of the mines and currently meets Ontario Drinking Water Standards.

Site rehabilitation

The Cluff Lake mine, located in the western Athabasca Basin of Saskatchewan, ceased mining and milling operations in May 2002. A two-year decommissioning programme was initiated in 2004, following a five-year comprehensive environmental assessment study. Decommissioning was essentially completed by 2006, followed by revegetation. The remaining buildings were demolished in 2013 and access to the site is no longer restricted. Orano conducts monitoring of the site every quarter.

In northern Saskatchewan, several mines (principally the Gunnar and Lorado mines) were operated from the late 1950s to early 1960s by private sector companies that no longer exist. When the sites were closed, there were no regulatory requirements in place to appropriately contain and treat the waste, which has led to environmental impacts on local soils and lakes. The responsibility for these sites is now held by the government of Saskatchewan and a project is currently underway to remediate these sites.

Uranium requirements

In 2020, nuclear energy provided about 15% of Canada's total electricity needs (including approximately 60% in Ontario and 40% in New Brunswick) and is expected to continue to play an important role in supplying Canada with electricity in the future. Canada has a fleet of 19 CANDU pressurised heavy water reactors, of which 17 are currently in full commercial operation (16 in Ontario and 1 in New Brunswick). Two reactors in Ontario (Darlington unit 3 and Bruce Power unit 6) were taken out of service in 2020 for refurbishment and are expected to return to service in 2023-2024. Two reactors in Ontario (Pickering 2 and 3) and one reactor in Quebec (Gentilly-2) have been shut down permanently for decommissioning.

In Canada, the responsibility for deciding on the energy supply mix and investments in electricity generation capacity, including the planning, construction and operation of nuclear power plants, resides with the provinces and their provincial power utilities.

Canada's CANDU nuclear reactors are designed to provide electricity generation for about 25-30 years. Through "refurbishment" (replacement of key reactor and station components), continued operation of the reactors can be extended for approximately 30 additional years. Refurbishment projects in New Brunswick (Point Lepreau) and Ontario (Bruce A units 1 and 2) have been completed and the reactors returned to service in the fall of 2012. More recently, as laid out in Ontario's 2013 Long-term Energy Plan, refurbishment of the first Darlington unit began in October 2016 and was completed on schedule in June 2020. Refurbishment of the second Darlington unit began in September 2020 with all four Darlington units expected to be refurbished by 2026 as planned and within budget. Similarly, the first Bruce unit refurbishment began in January 2020 and all six Bruce units are expected to be refurbished by 2033.

The Pickering Nuclear Generating Station, Ontario's first commercial-scale nuclear power plant, will not be refurbished once it reaches the end of its safe operating life. In 2018, approval was given for the continued operation of Pickering up to 2024.

In 2012, Canada's nuclear regulator, the Canadian Nuclear Safety Commission (CNSC), granted a site preparation licence for a nuclear new build at Darlington following approval of the environmental assessment. The licence is valid for ten years and the CNSC is currently considering an application to renew the licence, with the intention that the site be prepared for use as a demonstration of small modular reactor (SMR) technology. An SMR demonstration is also being considered at another site in Chalk River Ontario, located at Canada's nuclear laboratories, pending the licence to prepare the site.

In December 2020, the Minister of Natural Resources announced the release of Canada's SMR Action Plan, which was developed in partnership with more than 100 organisations, including seven provincial and territorial governments (Alberta, Saskatchewan, Ontario, New Brunswick, Prince Edward Island, Yukon, Nunavut), municipalities, utilities, industry, civil society, academia and some Indigenous voices. The Action Plan outlines progress and ongoing efforts by these organisations to support the development and deployment of SMRs, while responding to and going beyond recommendations in Canada's SMR Roadmap. In 2021, NRCan will continue to advance priorities outlined in the Government of Canada chapter of the Action Plan together with partners from across the government.

In December 2019, the Provinces of Alberta, Ontario, Saskatchewan and New Brunswick signed a memorandum of understanding to advance the demonstration and deployment of SMRs in Canada. The Province of Alberta formally became a signatory in April 2021. These provinces have agreed to collaborate on the advancement of SMRs as a clean energy option to address climate change and regional energy demands, while simultaneously supporting economic growth and innovation.

Supply and procurement strategy

Approximately 1 700 tU of Canada's uranium production is used domestically to generate nuclear power. The nuclear utilities fill uranium requirements through long-term contracts and periodic spot market purchases.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The Nuclear Fuel Waste Act (NFWA), which came into force on 15 November 2002, requires nuclear energy corporations to establish a Nuclear Waste Management Organization (NWMO) to manage nuclear fuel waste safely and securely over the long term.

Adaptive phased management (APM) was chosen as Canada's approach for safely managing nuclear fuel waste over the long term. APM involves the containment and isolation of nuclear fuel waste in a deep geological repository. The APM approach recognises that people benefiting from nuclear energy produced today must take steps to ensure that the wastes are dealt with responsibly and without unduly burdening future generations. At the same time, it is sufficiently flexible to adapt to changing social and technological developments. APM is implemented by the NWMO, using funds provided by the owners of nuclear fuel waste.

The NWMO has developed a siting process to identify an informed, willing host community with a safe, secure and suitable site for a deep geological repository. This nine-step siting process was collaboratively designed, refined and finalised through an iterative two-year public engagement and consultation process. In May 2010, the NWMO initiated the siting process with an invitation to communities to learn more about the APM project and the plan to safely manage the waste. By the end of 2014, the NWMO had actively engaged with 21 communities in Ontario and Saskatchewan, including First Nations and Métis communities that had expressed an interest in hosting the waste management facility. The ultimate success of the project depends upon community engagement and lasting partnerships.

In November 2019, the NWMO selection process was narrowed down to two potential siting areas: the Township of Ignace (north-western Ontario) and the Township of Huron-Kinloss/ Municipality of South Bruce (southern Ontario). Detailed fieldwork to address the scientific and technical aspects, as well as the social dimensions of site selection, will proceed over the next several years. Field studies, borehole drilling, airborne surveys, environmental mapping, socio-economic studies and other assessments will be carried out to determine the suitability of sites and the willingness of communities. The NWMO will continue to build and strengthen its working relationships with participating communities as this process advances.

The Nuclear Liability and Compensation Act (NLCA), which entered into force on 1 January 2017, replacing the Nuclear Liability Act of 1976, strengthens Canada's nuclear liability regime. It establishes the compensation and civil liability regime to address damages in the extremely unlikely event of a nuclear incident at a Canadian nuclear installation. It also enables Canada's implementation of the IAEA Convention on Supplementary Compensation for Nuclear Damage. By being a member of the Convention, Canada commits to harmonising its nuclear liability principles with those of other member countries and provides compensation for civil damages in other member countries resulting from a nuclear accident in Canada. Reciprocally, another member country would provide compensation for civil damages resulting from a nuclear accident in that country. The Convention also provides for the establishment of a pool of funds that would be available in the event of an accident, should it be required, to compensate for damage in countries that are members of the Convention.

The NLCA embodies the principles of absolute and exclusive liability of the operator, mandatory insurance and limitations on the operator's liability in both time and amount. Under the NLCA, the operator of a nuclear power plant is responsible to pay up to CAD 1 billion for civil damages resulting from an accident at that plant. The Act also established that the existing CAD 1 billion liability limit for nuclear installations must be reassessed at least once every five years and based on the assessment, the Government of Canada may increase the amount by regulation. The first review of the NLCA liability limit was undertaken in 2021.

Uranium stocks

The Canadian government does not maintain any stocks of natural uranium and data for producers and utilities are not available. Since Canada has no enrichment or reprocessing facilities, there are no stocks of enriched or reprocessed material in Canada. Although Canadian reactors use natural uranium fuel, small amounts of enriched uranium are used for experimental purposes and in booster rods in certain CANDU reactors.

Uranium prices

In 2002, Natural Resources Canada suspended the publication of the average price of deliveries under export contracts for uranium.

Uranium exploration and development expenditures and drilling effort – domestic

(CAD millions)

	2018	2019	2020	2021 (expected)
Industry* exploration expenditures	170	162	88	NA
Industry* development expenditures	94	114	105	197
Total expenditures	264	276	193	NA
Industry* exploration drilling (m)	260 640	188 954	NA	NA
Industry* exploration holes drilled	NA	NA	NA	NA
Industry* development drilling (m)	52 734	65 156	NA	NA
Industry* development holes drilled	NA	NA	NA	NA
Subtotal exploration drilling (m)	260 640	188 954	NA	NA
Subtotal exploration holes drilled	NA	NA	NA	NA
Subtotal development drilling (m)	52 734	65 156	NA	NA
Subtotal development holes drilled	NA	NA	NA	NA
Total drilling (m)	313 374	254 110	NA	NA
Total number of holes drilled	NA	NA	NA	NA

* Non-government.

Conventional reasonably assured resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	255 570	438 089	568 404	NA**
Open-pit mining (OP)	0	270	20 358	49 372	NA**
In situ leaching acid	0	26 487	31 213	31 213	NA**
Total	0	282 327	489 660	648 989	NA**

* Also known as stope leaching or block leaching. ** Mining losses (~10%) and ore processing losses (~3%) were used to calculate recoverable resources if recovery factors were not provided by companies.

Conventional reasonably assured resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	0	255 570	438 089	560 057
Conventional from OP	0	270	20 358	49 372
In situ leaching acid	0	26 487	31 213	31 213
In-place leaching*	0	0	0	5 426
Heap leaching** from UG	0	0	0	2 921
Total	0	282 327	489 660	648 989

* Also known as stope leaching or block leaching. ** A subset of open-pit and underground mining, since it is used in conjunction with them.

Conventional reasonably assured resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity	0	282 327	483 660	602 049
Sandstone	0	0	6 000	6 000
Paleo-quartz-pebble conglomerate	0	0	0	8 347
Metasomatite	0	0	0	32 593
Total	0	282 237	489 660	648 989

Conventional inferred resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	9 610	85 685	178 773	NA*
Open-pit mining (OP)	0	0	12 764	37 211	NA*
In situ leaching acid	0	415	415	415	NA*
Total	0	10 025	98 864	216 399	

* Mining losses (~10%) and ore processing losses (~3%) were used to calculate recoverable resources if recovery factors were not provided by companies.

Conventional inferred resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	0	9 610	85 685	164 882
Conventional from OP	0	0	12 764	37 211
In situ leaching acid	0	415	415	415
In-place leaching*	0	0	0	9 029
Heap leaching** from UG	0	0	0	4 862
Total	0	10 025	98 864	216 399

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Conventional inferred resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity	0	10 025	92 820	166 714
Sandstone	0	0	6 044	22 032
Paleo-quartz-pebble conglomerate	0	0	0	13 891
Intrusive	0	0	0	2 543
Metasomatite	0	0	0	11 219
Total	0	10 025	98 864	216 399

Conventional prognosticated resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
50 000	150 000	150 000

Conventional speculative resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
700 000	700 000	0

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (actual)
Open-pit mining*	119 566	0	0	119 566	0
Underground mining*	412 359	6 944	3 878	423 181	4 692
Total	531 925	6 944	3 878	542 747	4 692

* Pre-2018 totals includes ~1 000 tU recovered by in-place leaching. 2014-2017 underground mining totals include 61 tU recovered at the Key Lake mill from recycling uranium refinery wastes.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (actual)
Conventional	530 925	6 944	3 878	541 747	4 692
In-place leaching*	1 000	0	0	1 000	0
Total	531 925	6 944	3 878	542 747	4 692

* Also known as stope leaching or block leaching.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (actual)
Proterozoic unconformity	356 018	6 944	3 878	366 840	4 692
Paleo-quartz-pebble conglomerate	144 182	0	0	144 182	0
Granite-related	7 539	0	0	7 539	0
Intrusive	5 636	0	0	5 636	0
Metasomatite	18 489	0	0	18 489	0
Other/unspecified*	61	0	0	61	0
Total	531 925	6 944	3 878	542 747	4 692

* Uranium recovered at Key Lake mill from recycling uranium refinery wastes.

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
0	0	1 939	50	1 435	37	504	13	3 878	100

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres	1 844	1 824	1 934	N/A
Employment directly related to uranium production	831	913	746	N/A

Mid-term production projection (tonnes U/year)

2021	2022	2025	2030	2035
<6 900	8 400	13 900	15 000	15 000

Mid-term production capability

(tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
12 330	18 850	12 330	18 850	12 330	22 000	15 000	30 000

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
12 330	18 850	15 000	30 000	12 330	18 850	15 000	30 000

Net nuclear electricity generation

	2019	2020
Nuclear electricity generated (TWh net)	95.5	92.7

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
12 700	11 900	8 500	8 500	10 200	10 200	11 100	11 100	11 100	11 100

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
1 770	1 715	1 160	1 210	1 395	1 430	1 525	1 650	1 525	1 630

* Uranium requirements calculated assuming 18.5 tU per TWh (net) electrical generation.

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	0	0	0	0	0
Producer	NA	0	0	0	NA
Utility	NA	0	0	0	NA
Total	NA	0	0	0	NA

Central African Republic*

Uranium exploration and mine development

Historical review

France's Alternative Energies and Atomic Energy Commission (CEA) was the first organisation to prospect for uranium in the Central African Republic. Initial reconnaissance work commenced in 1947 and exploration of the extensive zones of crystalline formations which border the west and occupy the centre of the country was conducted without success. In 1956, prospecting using improved techniques and benefiting from improved knowledge of uranium metallogeny was extended to the detrital siliceous series of the Middle Precambrian-Upper Precambrian (Nbafkl and Fouroumbala Series). A major radiometric anomaly was discovered in the N'zako laterites, but importantly, a significant geological similarity was noted between the Fouroumbala Series and Franceville in Gabon, where a uranium deposit had been discovered. Encouraged by this similarity, the CEA intensified its exploration in 1959 with a systematic programme of aerial prospecting, covering the entire eastern region of the country, an area of around 50 000 km². This work led, in 1961, to the discovery of the country's first uranium deposit near the town of Bakouma. Three deposits were discovered. Geologically, the host is a uranium-bearing phosphatic formation of the Eocene age. The notable feature is the exceptionally high uranium content for a formation of this type. In 1963, the CEA and the Compagnie Française des Minéraux d'Uranium (CFMU) formed a syndicate to continue exploration and to study the feasibility of mining the deposit. A jointly owned mining company, the Bakouma Uranium Mining Company (URBA), was set up in 1969 between the state and the CEA and CFMU partnership. However, the result of the feasibility study on the mining of the deposit was unfavourable, as the phosphatic nature of the ore made it difficult to develop a suitable processing method, and activities by URBA ceased in 1971.

After the oil crisis in the winter of 1973-1974, numerous foreign companies showed interest in the Bakouma deposit, and Aluminium Suisse S.A. of Zurich resumed studies on the mining of the deposit. In February 1975, a new mining company (URCA, Central African Uranium Company) was set up between Aluminium Suisse and the three original partners of URBA. Prospecting conducted by the Atomic Energy Commission, URBA, and URCA used the following methods: (a) geological investigation and cartography; (b) airborne radiometric surveys; (c) ground radiometric surveys; (d) ground verification of selected anomalous zones; (e) drilling of boreholes at different spacing intervals; (f) geochemical analysis of soil, water and alluvial sediments. However, subsequent technical, metallurgical, and economic studies indicated that the deposits were not economically viable at the then prevailing price of uranium, and in 1978 the project was terminated.

In May 2006, UraMin Inc. was granted one mining permit and two research permits for the exploration of uranium mineralisation in the Bakouma region. Reverse circulation percussion drilling commenced at the Patricia deposit in August 2006 to confirm the presence of uranium mineralisation and to increase the known resource. Initial drilling of 66 holes on a 100 m × 50 m grid spacing delineated the extent of the Patricia deposit. Data from these holes were used as the basis for the resource estimate. Reverse circulation infill drilling on a 50 m × 50 m grid spacing commenced and a diamond drilling campaign to acquire additional geological and geotechnical information was also planned. Further reverse circulation and diamond drilling were planned at the other deposits that comprise the Bakouma project.

* Report prepared by the NEA/IAEA, based on previous Red Books and company reports.

On 30 July 2007, the owner of Bakouma and other African uranium deposits, UraMin Inc., was acquired by Areva (now Orano) for USD 2.5 billion. This transaction gave Areva a 90% interest in the project, with a 10% carried interest retained by the state. The start-up of the Bakouma pilot project was planned for 2010. In June 2012, gunmen attacked the Bakouma project site and since then all activities have been suspended.

Recent and ongoing uranium exploration and mine development activities

There has been no recent exploration and mining development for uranium in the Central African Republic.

Uranium resources

The uranium mineralisation of the Bakouma Basin is associated with phosphate lenses intercalated with silts and siliceous horizons. It is these lenses that have the highest concentrations of uranium mineralisation and they are grouped into several deposits: Palmyre, Pama, Pamela, Pâquerette, Patou and Patricia, which make up the greater Bakouma deposit.

Identified conventional resources

In its 2020 annual report, Orano reported the results of a new resource evaluation that shows inferred in situ resources amounting to 36 475 tU at an average grade of 0.20 %U.

In previous Red Book editions, the Central African Republic reported 42 200 tU as RAR in situ resources, in the < USD 260 cost category.

Unconventional resources

The Central African Republic does not report unconventional resources. While the Bakouma uranium deposit is associated with phosphates, it is classified as a conventional deposit because of the relatively high (0.15-0.30% U) uranium grade.

Uranium production

The start-up of the Bakouma pilot project was planned for 2010. It aimed to start open-pit mining at 1 200 tU/yr. At full capacity, the mine would have produced 2 000 tU per year. The Areva group suspended the uranium mining project at the end of 2011 for one to two years due to low uranium prices and the need for further research on the metallurgy. In June 2012, gunmen attacked the Bakouma uranium mine project site, and since then all activities have been suspended.

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open pit	0	0	0	36 475	NA
Total	0	0	0	36 475	NA

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Phosphate	0	0	0	36 475
Total	0	0	0	36 475

Chile*

Uranium exploration and mine development

Historical review

Uranium exploration began in the 1950s with the US Atomic Energy Commission conducting a review of uranium potential in mining districts with Cu, Co, Mo, Ag mineralisation. Following a delay of about ten years, activities were renewed in 1970 by the Spanish Nuclear Energy Organisation, focusing for four years on Region IV of the Tambillos mining district.

Between 1976 and 1990, regional prospecting encompassing an area of 150 000 km^2 was conducted in co-operation with the International Atomic Energy Agency using geochemical drainage surveys, aerial radiometry, ground-based geology and radiometry. This work led to the detection of 1 800 aerial anomalies, 2 000 geochemical and radiometric anomalies and the definition of 120 sectors of interest. Subsequent investigation of 84 of these sectors of interest led to the identification of 80 uranium occurrences, stimulating further study of the 12 most promising prospects, preliminary exploration of these prospects, and eventually the evaluation of uranium resources as a by-product of copper and phosphate mining.

From 1980 to 1984, Cía Minera Pudahuel (the Pudahuel Mining Company), in co-operation with the Chilean Nuclear Energy Commission (CCHEN), conducted drilling of the Sagasca Cu-U deposit, Region I (Tarapacá), leading to a technical and economic evaluation of the Huinquintipa copper deposit, Region I. The Production Development Corporation (Corporación de Fomento de la Producción – CORFO) and the CCHEN conducted exploration and technical economic evaluation of the Bahía Inglesa phosphorite deposit, Region III (Atacama), in 1986 and 1987.

Between 1990 and 1996, the CCHEN undertook geological and metallogenic uranium research, mainly in the north of the country. From 1996 to 1999, the CCHEN and the National Mining Company of Chile (ENAMI) investigated REE in relation to radioactive minerals in the Atacama and Coquimbo regions. Dozens of primary occurrences were studied, with the "Diego de Almagro" Anomaly-2 chosen as a priority. The study of this 180 km^2 sector found disseminations and veins of davidite, ilmenite, magnetite, sphene, rutile and anatase, with 3.5 to 4.0 kg/t of REE oxides (REO), 0.3 to 0.4 kg/t of U and 20 to 80 kg/t of Ti. The geological resources of the ore contained in this prospect were estimated at 12 000 000 t. The metallurgical recovery of REO from these minerals was also considered during an investigation of mining resources with economic potential in the medium term.

In 1998 and 1999, the CCHEN created the National Uranium Potential Evaluation Project, encompassing the activities of uranium metallogeny research and development of a geological database. The aim of this project was to set up a portfolio of research projects to improve the evaluation of national uranium ore potential. Between 2000 and 2002, a preliminary geological evaluation for uranium and REO of the Cerro Carmen prospect (2000-2002), located in Region III (Atacama), was completed as part of the specific co-operation agreement between the CCHEN and ENAMI. Geophysical exploration work was undertaken (magnetometry, resistivity and chargeability), defining targets with metallic sulphur minerals with uranium and associated REE.

In 2001, a project portfolio document was developed that updated the metallogeny and geological favourability for uranium in Chile. A total of 166 research projects were proposed, ranging from regional activities to detailed scientific studies, to be undertaken sequentially in

* Report prepared by the NEA/IAEA, based on previous Red Books, government data and company reports.

accordance with the CCHEN capacities. In the extractive metallurgy area, work has been ongoing since 1996, through a co-operation agreement between the CCHEN and ENAMI, to develop processes to produce commercial concentrates of rare earths. High purity concentrates of light REE, as well as yttrium, have been obtained.

In 2003, regional reconnaissance was undertaken for uranium and REE in Region I of the country, after which the CCHEN-ENAMI co-operation agreement was terminated. Through 2004, database work was continued by the CCHEN, and commercial services were provided to the mining industry through 2010.

From 2008 to 2012, the CCHEN completed a broad scope co-operation agreement with the National Copper Corporation (CODELCO Norte) for geological and metallurgical investigation of natural radioactive material occurrences. From 2009 to 2012, the CCHEN and CODELCO Norte completed an agreement on activities to investigate recovery of uranium and molybdenum from copper ore leaching solutions.

Recent and ongoing uranium exploration and mine development activities

No uranium exploration and mine development activities have been carried out in recent years.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

No new uranium resources have been identified since the 2011 edition of the Red Book. Recoverable identified resources (RAR + IR) total 1 448 tU in the <USD 260 kg/U cost category.

Undiscovered conventional resources (prognosticated and speculative resources)

Prognosticated and speculative in situ conventional resources remain at 2 324 tU (<USD 260/kgU) and 2 360 tU (unassigned cost category), respectively. Undiscovered conventional resources account for a total of 4 684 tU.

Unconventional resources and other materials

Identified unconventional recoverable resources account for 1 169 tU (<USD 260/kgU), while undiscovered unconventional resources total 5 458 tU in situ. New unconventional resources have not been reported.

Identified conventional resources (reasonably assured and inferred resources)

(in situ tonnes U)

Deposit	Type	RAR	IR	Grade % U_3O_8	Rocks, hosting age
Cenozoic surficial deposits[1]	Surficial	28	40	0.023	Diatomite, volcanic ash with organic material (Pliocene – Pleistocene)
Cretaceous metasomatic[2]	Metasomatic	720	1 043	0.028-0.20	Intrusive, volcanic and metasomatic rocks (upper Cretaceous)
Cenozoic volcanic-related[3]	Volcanic-related	0	100	0.01-0.18	Magnetite and haematite tuffs. Secondary U-REE mineralisation (Oligocene Pleistocene)
Total		748	1 183		

Surface deposits:

1. Salar Grande (28 tU), Mina Neverman (?), Boca Negra (3 tU), Manuel Jesús (2.5 tU), Mina Casualidad (?), Mina San Agustín (?), Quebrada Vítor (?), Pampa Chaca (2 tU), Pampa Camarones (3.5 tU), Quebrada Amarga (2 tU), Quillagua (22 tU), Prosperidad (?), Chiu Chiu (5 tU).

Metasomatic deposits:

2. Estación Romero 326 tU (Carmen and Productora prospects), Cerro Carmen prospect (1 391.8 tU), Agua del Sol (15 tU), Sector Pejerreyes – Los Mantos (20 tU), Tambillos district (10 tU). The following estimates were produced at the prospect of the Diego de Almagro Anomaly-2 (Cerro Carmen prospect) in 1999-2000, as a result of detailed geological and radiometry work, together with magnetometry, excavation and sampling of exploration trenches, undertaken as part of the activities of the co-operation agreement between ENAMI and the CCHEN: Calculations indicate that the deposit hosts a total of 595.3 tU as indicated resources, 796.5 tU as inferred resources, making a total in situ of 1 391.8 tU as identified resources (RAR + inferred). The cost of extracting these resources was not estimated, therefore not included in the identified resources tables.

Volcanogenic deposits:

3. In the El Laco iron ore deposit, produced during Cenozoic volcanism on the "altiplano" of Region II (Antofagasta), a total of 100 tU (in situ) was identified as inferred.

Uranium resources by deposit type

(in situ tonnes U)

Deposits, areas and other resources	RAR + IR	PR + SR	SR*
Surficial deposits	68.0	123.5	
Metasomatic deposits	1 762.8	4 060.0	
Volcanic-related deposits	100.0	500.0	
Unconventional deposits and resources	1 798.0	5 458.0	1 000
Deposit areas:			
1 – Surface deposits, Cenozoic	--	--	500
2 – Metasomatic deposits, Cretaceous	--	--	500
3 – Magmatic deposits, Cenozoic			250
4 – Polymetallic deposits, Cretaceous	--	--	100
Favourable areas:			
A – Acid volcanism, Tertiary	--	--	500
B – Intrusives, Jurassic-Cretaceous	--	--	500
C – Volcanic acid-sedimentary, Cretaceous	--	--	200
D – Main Cordillera, Palaeozoic magmatism	--	--	50
E – Sedimentary-volcanic, Middle Cretaceous	--	--	100
F – Nahuelbuta, Palaeozoic plutonism	--	--	300
G – Clastic sedimentary, Cretaceous-Tertiary	--	--	300
Total	3 728.8	10 141.5	4 300

* Undiscovered resources are expected to exist remotely from the known occurrences, either in the aforementioned uranium deposit areas or in favourable areas. In the case of unconventional resources, the figures correspond to uranium that could be recovered from the copper leaching plant solutions of the country's medium and large-scale mining activities. The latter could be several orders of magnitude greater, considering that large-scale national mining, both state-owned and private, produces large reserves of minerals in projects lasting up to 20 years. The CCHEN has not updated its studies on this subject.

Surficial deposits

(in situ tonnes U)

Surface deposits	RAR	IR	PR	SR	% U_3O_8	Minerals
Boca Negra		3.0			0.02-0.600	Silica, yellow minerals
Manuel Jesús		2.5			0.10-0.190	Silica, yellow minerals
Casualidad					0.018	Silica, yellow minerals
San Agustín					0.20-0.250	Silica, yellow minerals
Poconchile					0.028	Silica, yellow minerals
Quebrada Vítor					0.028	Autunite
Pampa Chaca		2.0			0.028	Autunite
Pampa Camarones		3.5	3.5		0.030	Autunite, shronquingierite
Salar Grande	28.0		100.0		0.023	Carnotite
Quebrada Amarga		2.0			0.117	Carnotite
Quillagua		22.0			0.165	Carnotite
Chiu Chiu		5.0	5.0	15.0	0.04-0.140	Yellow minerals
Total	28.0	40.0	108.5	15.0		

Metasomatic deposits

(in situ tonnes U)

Metasomatic and hydrothermal deposits	RAR	IR	PR	SR	% U_3O_8	Minerals
Anomaly-2, Diego de Almagro (Cerro Carmen prospect)	595.3	796.5	1 400.0	1 500.0	0.03-0.10	Davidite, sphene, Ilmenite, anatase
Agua del Sol	15.0			50.0	0.02-0.06	Davidite
Sierra Indiana			15.0	15.0	0.02-0.08	Davidite
Estación Romero						
Carmen	20.0	10.0		50.0	0.01-0.12	Davidite
Producer	60.0	236.0	300.0	500.0	0.01-0.28	Autunite, torbernite
Tambillos	10.0			100.0	0.01-0.20	Uraninite, pitchblende
Pejerreyes – Los Mantos	20.0			130.0	0.01-0.05	Davidite, aut., torbernite
Total	720.3	1 042.5	1 715.0	2 345.0		

Volcanic-related deposits

(in situ tonnes U)

Volcanogenic deposits	RAR	IR	PR	SR	% U_3O_8	Minerals
Acid and intermediate volcanism, regions I to III						Not investigated
El Laco sector, Region II		100	500			Aut., torbernite, REE
El Perro sector, Region III						Not investigated
Total		100	500			

Unconventional resources and other materials*

(in situ tonnes U)

Mines, prospects, materials	RAR	IR	PR	SR	% U_3O_8	Minerals
Copper-uranium paleochannels						
Sagasca – Cascada[1]	164				0.0046	Crisocola, U
Huinquintipa[2]	46				0.0030	Crisocola, U
Chuquicamata Sur[3]	950				0.0007	Crisocola, U
Quebrada Ichuno[4]				25	0.0060	Crisocola, U
El Tesoro[5]				50	0.0070	Crisocola, U
North Chuquicamata (oxides zone)[6]				1 000	0.0008	Oxides Cu, U
Gravel from Chuquicamata oxides plant[7]				2 000	0.0008	Oxides Cu, U
Seams of high-temperature copper						
Algarrobo – El Roble[8]			513		0.0400	Sulph., Cu, U
Carrizal Alto[8]				500	0.0250	Sulph., Cu, U
Tourmaline breccias[8]						
Campanani[8]						
Sierra Gorda[8]				60	0.0020	Sulph., Cu, U
Los Azules[8]			5			
Cabeza de Vaca[8]				5		
Uranium-bearing phosphorites						
Mejillones			1 300		0.0026	Colophane – U
Bahía Inglesa[9]	638				0.0062	Colophane – U
Total	1 798		1 818	3 640		

* Note: The figures shown in this table represent historical data and are not current. Studies need to be done to validate or eliminate these figures.

1. The Sagasca deposit is exhausted, the Cascada deposit (continuation of the mineralised body) is practically exhausted; however, new explorations in the area have found new mineralised bodies, so the figure could vary substantially.
2. Huinquintipa currently forms part of the Collahuasi Project, a contractual mining company belonging to Anglo American Plc and Xstrata Copper, a division of the Swiss mining company Xstrata Plc, each of which has a 44% stake. The remaining 12% belongs to JCR, a consortium of Japanese companies led by Mitsui & Co., Ltd. The oxidised mineral reserves amount to 53 million tonnes, for which copper extraction and production began in 2000 and will last for 20 years. The figures shown in the foregoing table could rise by a factor of between 10 and 20.
3. Chuqui Sur: Although this deposit is not exhausted, the surcharge makes it expensive to operate, so the uranium resources contributed to the Chuquicamata Division oxides plant could be zero. Accordingly, the figures indicated above could decrease significantly.
4. Quebrada Ichuno, has not been studied and there are only preliminary works, so the figure mentioned above is maintained.
5. The uranium resources assigned to the El Tesoro mine correspond to preliminary geological reconnaissance data obtained in 1983. This deposit is currently a nationally important mining centre, 70% owned by Antofagasta Minerals S.A., which belongs to Antofagasta Plc, and 30% owned by the Marubeni Corporation of Japan. Its mineral reserves amount to 186 million tonnes, with a useful life of 21 years. Preliminary samples suggest uranium contents of between 5 and 200 ppm, with an average of between 15 and 20 ppm. Investigating this uranium source could change the figure indicated above substantially.
6. The "Chuquicamata Norte" prospect currently corresponds to the Radomiro Tomic mining centre, with reserves of 970 million tonnes of minerals that could be leached from copper and a useful life of 22 years. A programme of activities is currently being developed to recover uranium and molybdenum.
7. Estimations performed in the 1970s assigned a potential of 1 000 tU that could be recovered from copper leaching solutions obtained from the gravels of the old oxides plant of the Chuquicamata copper mine. This project began its activities in 1998 and will be active for 12 years. By the end of the period it will produce 467 000 t of fine copper. Recovery of uranium from these leaching solutions has not been researched.

   In addition to the uranium resources present in the leaching solutions from the aforementioned mines, there are other large copper deposits in the large-scale mining sector, whose leaching solutions have not been researched. An example is El Abra. This deposit, owned by Phelps Dodge Mining Co (51%) and CODELCO Chile (49%), started production of 800 million tonnes of is copper minerals for a 17-year period.
8. These figures have historical value only and as geological background data. The low copper content of these districts and the small volume of their reserves makes it difficult to recover their uranium content.
9. No experiments have been done to recover uranium from the uranium content in marine phosphorites. The only deposit currently being exploited is Bahía Inglesa, in Region III (Atacama), which produces a solid phosphate concentrate of direct use as fertiliser. In 2001, Compañía Minera de Fosfatos Naturales Ltda., (BIFOX LTDA.), which operates the aforementioned mine, began producing phosphoric acid, which would make it possible to recover uranium from the mother solutions.

Unconventional resources and other materials

(in situ tonnes U)

Deposit	RAR	IR	PR	SR	% U	Mineral
Unconventional	1 798	0	1 818	3 640	0.0008-0.1	Leaching solution 7 to 15 g/m^3 Oxide plants gravel Cu silicate and oxides, 20-70 ppm Sulphur oxide veins of 500-1 000 ppm
Total	1 798	0	1 818	3 640		

Speculative resources in uranium geological favourable areas

Growing knowledge of the distribution of uranium mineralisation in Chile has made it possible to define four areas of uranium occurrence and seven favourable areas, five of which have occurrences of uranium, collectively accounting for potential resources of 3 300 tU.

Areas of uranium occurrences, accounting for ~1 350 tU:

1. Upper Cenozoic surface deposits – potential in SR: 500 tU.
2. Upper Cretaceous metasomatic deposits – potential in SR: 500 tU.
3. Upper Cenozoic magmatic and hydrothermal deposits – potential in SR: 250 tU.
4. Upper Cretaceous polymetallic and uranium deposits – potential in SR: 100 tU.
5. Tertiary volcanogenic deposits – potential not investigated.

Areas favourable for uranium occurrences, accounting for 1 950 tU (only minimum potential is indicated owing to a lack of research):

A. Acid volcanism and tertiary-quaternary alluvial deposits, Main Cordillera, Regions I and II – potential: 500 tU.

B. Intrusive Jurassic and Cretaceous rocks, Coastal Range, regions I and II – potential: 500 tU.

C. Acid volcanism and upper Cretaceous clastic sedimentary rocks; Central Valley, regions II and III – potential: 200 tU.

D. Paleozoic magmatism, Main Cordillera, Region IV – potential: 50 tU.

E. Sedimentary-volcanic rocks of the Middle Cretaceous period, neogenic intrusives, Main Cordillera, regions VI, VII and Metropolitan Region – potential: 100 tU.

F. Nahuelbuta Range, Paleozoic plutonism, regions VIII and IX – potential: 300 tU.

G. Acid and intermediate sedimentary clastic volcanism, Tertiary, Main Cordillera, regions VII, VIII and IX – potential: 300 tU.

Undiscovered conventional resources (prognosticated and speculative resources)

Deposit	Type	Prognosticated tonnes U	Speculative tonnes U	Grade % U	Rocks hosting age
Diatomite, volcanic ash with organic material[1]	Surficial	108.5	15.0		Pliocene – Pleistocene
Intrusive, volcanic and metasomatic rocks[2]	Metasomatic	1 715	2 345	0.025-0.17	Upper Cretaceous
Tuffs with high magnetite and haematite content. Mineralisation of secondary REE minerals observed[3]	Volcanic-related	500	0*	0.085-0.15%	Oligocene – Pleistocene
Total		2 323.5	2 360*		

* 2 360 tU represents the speculative resources as tabulated and summed across the surficial deposits, metasomatic deposits and volcanic-related deposits tables. However, it does not take into account an additional 940 tU of speculative resources (for a total of 3 300 tU) indicated elsewhere in the report (see section "Speculative resources in uranium geological favourable areas" and table "Uranium resources by deposit type").

1. Salar Grande (100 tU), Pampa Camarones (3.5 tU), Chiu Chiu (20 tU).

   No new uranium prospecting has been done in the area of Cenozoic surface deposits.

2. Diego de Almagro Anomaly-2 (1 400 tU); Diego de Almagro Alignment (1 500 tU); Agua del Sol (50 tU), Sierra Indiana (30 tU), Sector Estación Romero: Carmen prospect (50 tU) and Productora Prospect (800 tU), Tambillos district (100 tU), Sector Pejerreyes – Los Mantos (130 tU).

   In 1999-2000, at the Diego de Almagro Anomaly-2 (Cerro Carmen prospect), 1 400 tU was assigned as prognosticated and speculative undiscovered resources. The regional alignment that controls the mineralisation of this prospect extends 60 km to the north-west. This structure, visible in satellite images, involves other mining districts for which a potential of 1 500 tU of speculative resources is assigned.

3. In 1999-2000, data held by the CCHEN was reviewed as part of the National Uranium Potential Evaluation Project. It was concluded that the acidic and intermediate volcanism present in a broad area of the Main Cordillera stretching from regions I to III constituted an inclined plane dipping towards the west, ending in a lagoon environment situated in a central depression, with a similar condition occurring to the east. This volcanism covered the pre-volcanic landscape, preserving the surface drainage courses (now paleochannels). The leaching of these volcanic rocks contributed large amounts of uranium into the lagoon systems, paleochannels and other structures in which solutions circulate. This process is represented by extensive layers of calcilutites, diatomites (Pampa Camarones), layers of salt (Salar Grande), argillites, limestones, limolites and volcanic ash (Quillagua, Prosperidad, Quebrada Amarga, Chiu Chiu), with uranium contents ranging between 100 and 1 000 ppm. These uranium occurrences and mineralisations have been classified historically as "surface deposits". There are also paleochannels with copper and associated uranium (the Sagasca, Cascada, Huinquintipa, Quebrada Ichuno, Chuqui Sur, El Tesoro deposits and others). Within the volcanic area, uranium mineralisation (torbernite and autunite) has been discovered in volcanic structures containing iron (El Laco and El Perro). This environment is considered to have great potential and requires further research. In structures associated with the U mineralisation indicated above, 500 tU is assigned as EAR-II (now prognosticated).

Uranium production

Historical review

The uranium present in copper oxide ores could be recovered from the leaching solutions. A pilot-level trial was conducted in the Chuquicamata Division between 1976 and 1979, obtaining 0.5 t of yellow cake from copper-rich solutions containing 10 to 15 ppm U (0.001 to 0.0015% U), which was sent for purification at the CCHEN metallurgy pilot plant at the Lo Aguirre nuclear centre. The production of copper oxide minerals has quadrupled in Chile over the last decade.

The copper mining industry, particularly large-scale mining, has strategic (sub-economic) uranium potential in the large volumes of copper oxide leaching solutions. These resources are assigned a potential of 1 000 tU in mining centres not included in the previous table. However, no background studies have been performed to confirm these figures, either as mining resources or in terms of the volumes of solutions treated annually, so the information should be treated as unverified. Over the last decade, private firms, both domestic and foreign, have explored 12 "exotic copper" deposits in Chile, which correspond to paleochannels filled with gravel, mineralised with copper silicates, oxides and sulphates as a result of the natural leaching of porphyry copper deposits or other contribution areas. These mineralised bodies contain variable uranium contents ranging between 7 and 116 ppm (0.007 to 0.016% U). The leaching solutions in the plants that treat these copper oxide minerals display uranium levels of up to 10 ppm. This uranium content is technically recoverable using ion-exchange resins, at a likely production cost of over USD 80/kgU.

There has been no experience in recovering uranium from phosphorites in Chile. The only deposit currently being worked is Bahía Inglesa in Region III (Atacama), which produces a solid phosphate concentrate used directly as fertiliser. In 2001, Compañía Minera de Fosfatos Naturales Ltda. (Bifox Ltda.) began producing phosphoric acid from this deposit, opening the potential of recovering uranium from the acid.

Status of production capability and recent and ongoing activities

Other than the trial production mentioned above, no uranium has been produced in Chile.

Environmental activities and socio-cultural issues

The CCHEN runs a permanent programme to disseminate information on peaceful uses of nuclear energy, attached to the Office of Dissemination and Public Relations (Oficina de Difusión y Relaciones Públicas).

Regulatory regime

In Chile, there is no regulatory framework for uranium production cycle activities.

Uranium requirements

Chile has achieved significant technological development in the manufacture of MTR-type (materials test reactor) combustible elements, based on U_3Si_2 (uranium silicide). In March 1998, the manufacture of 47 combustible elements began at the CCHEN combustible elements plant, ending in 2004. For this work, 60 kg of metallic uranium was purchased from Russia, enriched to 19.75% in ^{235}U, covering uranium requirements up to the indicated date. At the present time, 47 combustible elements have been manufactured, 16 of which are operating in the RECH-1 reactor. Another was sent to the Petten Research Centre in the Netherlands to be classified under radiation in the high-flow reactor, which ended in November 2004.

Supply and procurement strategy

Should other loads of combustible elements be required, consideration will be given to purchasing enriched metallic uranium.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

There have been no changes in legislation relating to uranium in Chile.

Uranium stocks

There are no uranium stocks.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	561	75
Total	0	0	0	561	75

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	561	75
Total	0	0	0	561	75

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Metasomatic	0	0	0	540
Surficial	0	0	0	21
Total	0	0	0	561

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	887	75
Total	0	0	0	887	75

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	887	75
Total	0	0	0	887	75

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Volcanic-related	0	0	0	75
Metasomatic	0	0	0	782
Surficial	0	0	0	30
Total	0	0	0	887

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	2 324

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	2 360

Reasonably assured unconventional resources by mining method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	1 169	65
Total	0	0	0	1 169	65

Reasonably assured unconventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Co-product/by-product	0	0	0	1 169	65
Total	0	0	0	1 169	65

Reasonably assured unconventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Intrusive (porphyry copper)	0	0	0	754
Phosphate	0	0	0	415
Total	0	0	0	1 169

Prognosticated unconventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	1 818

Speculative unconventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	3 640

China (People's Republic of)*

Uranium exploration and mine development

Historical review

Uranium exploration and mining in China started in the mid-1950s. Prior to the 1990s, uranium exploration mainly focused on granite-related or volcanic-related hydrothermal deposits in Jiangxi, Hunan, Guangdong and Guangxi in South China. Over four decades, exploration by the Bureau of Geology (BOG), a subsidiary of the China National Nuclear Corporation (CNNC), resulted in the identification of most of the ore fields (deposits), such as Xiangshan, Xiazhuang, Zhuguang, Ujing and Miaoershan. Except for a few large deposits, most are relatively small and typically mid- to low-grade. Additionally, the deposits are mostly located in remote mountain areas, so mining costs are high.

At the beginning of the 1990s, when China initiated its nuclear energy programme, domestic demand for uranium increased very little due to the small number of nuclear power plants. Given that there was an oversupply of natural uranium in the international market during that period, China slowed its uranium exploration activities and drastically cut its uranium exploration expenditures.

In the late 1990s, as nuclear power plant construction in China accelerated, domestic demand for uranium steadily increased. Since then, year-over-year national expenditures on uranium exploration gradually increased, and the targets shifted from conventional hardrock mining in Southern China to in situ leaching (ISL) sandstone-type deposits in Meso-Cenozoic sedimentary basins in northern China, such as in the Yili, Turpan-Hami, Junggar, Erlian, Erdos and Songliao Basins. From 2000 to 2006, annual drilling gradually increased from 40 000 m to 250 000 m. Since 2006, investment in uranium exploration increased, with drilling peaking at 900 000 m in 2012.

In addition to the CNNC, which has been the major organisation involved in uranium exploration in China, the China National Petroleum Corporation (CNPC) also carried out uranium exploration in Tongliao, Inner Mongolia, in the late 1990s. Since 2008, Uranium Resources Co. Ltd, a subsidiary of the China General Nuclear Power Corporation (CGN), has also been active in domestic uranium exploration and has carried out related activities along the northern margin of Tarim Basin, Xinjiang and in Guangdong Province.

Domestic uranium exploration continued in 2017 and 2018 with positive results. The exploration focused on sandstone-type uranium deposits in north China, where resources were expanded in the Erdos, Yili and Songliao Basins. Uranium mineralisation was discovered in new areas in the Songliao, Junggar and Erlian Basins. Preliminary exploration indicates that these areas have high potential. Progress has also been made in the exploration of the deeper parts and periphery of the known uranium ore fields in south China.

Exploration, including regional uranium potential assessments and further work on previously discovered mineralisation and deposits in northern China, has principally been focused on medium to large sedimentary basins, including the Yili, Turpan-Hami, Junggar and Tarim Basins in the Xinjiang Autonomous Region; the Erdos, Erlian, Songliao, Badanjili and Bayingebi Basins in Inner Mongolia; the Caidamu Basin in Qinghai Province and the Jiuquan Basin in Gansu Province. Geologic surveys, radiometric surveys, and electromagnetic surveys

* Report prepared by the NEA/IAEA based on previous Red Books, available public information and NEA/IAEA estimates.

were combined with a moderate amount of drilling and shallow seismic methods to delineate prospects for further investigations. Further drilling was carried out in mineralised areas to identify ISL sandstone-type deposits, as well as sandstone/mudstone-type deposits with low permeability to be exploited by conventional mining.

Exploration in Southern China is mainly directed at identifying metallogenic belts relating to volcanic-related and granite-related deposit types, mostly distributed in the Xiangshan uranium ore field in Jiangxi Province, the Xiazhuang and Zhuguang uranium ore fields in Guangdong Province, and the Miaoershan uranium ore field in the Guangxi Autonomous Region.

The total drilling completed in 2017 and 2018 amounted to about 610 000 m and 580 000 m, respectively. As a result, uranium resources in sedimentary basins in northern China, such as the Yili, Erdos, Erlian and Songliao Basins, have increased. In Southern China, there have been small increases of uranium resources in the deeper parts and on the periphery of the Xiangshan, Miaoershan, Zhuguangnanbu and Xiazhuang uranium ore fields.

Recent and ongoing uranium exploration and mine development activities

No public information on recent domestic uranium exploration activities and expenditures in China is available for 2019 and 2020. For the purposes of this report, it is assumed that exploration continued at a similar pace as in 2018 within sedimentary basins in northern China and Inner Mongolia, and continued to be focused on new resource estimates related to sandstone-type ISL amenable deposits. See the 2020 edition of the Red Book for domestic and non-domestic uranium exploration and development expenditures as of 1 January 2019.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2021, identified in situ uranium resources in China totalled 339 500 tU, including 154 470 tU reasonably assured resources (RAR) and 185 030 tU inferred resources, assuming that no new resources have been discovered since the end of 2018. Compared to the 2020 edition, there is a slight decrease in RAR resources by 4 500 tU due to mining depletion in 2019 and 2020. Inferred resources have remained unchanged from 2019. Approximately 58% of all identified resources are amenable for ISL mining and 55% belong to the cost category of <USD 80/kgU. In this cost category, 91% of the resources are amenable to ISL mining and the rest for conventional underground mining.

The following table shows the distribution of uranium resources over 21 uranium ore fields, basins and deposits in 13 provinces or autonomous regions as of 1 January 2019. It has not been updated due to the lack of public information on recent exploration activities and mining depletion in 2019 and 2020.

Undiscovered conventional resources (prognosticated and speculative resources)

China has conducted systematic nationwide uranium resource prediction and evaluation with prognosticated resources estimated to amount to around 2 million tU. Favourable target areas for uranium mineralisation include the Erlian, Erdos, Tarim, Junggar, and Songliao Basins in northeast China, and the periphery at the depth of the known uranium deposits in Southern China. With further exploration in uranium metallogenetic prospective areas, more uranium resources are expected to be discovered.

Unconventional resources and other materials

There are unconventional uranium resources associated with phosphate rocks in China, mainly distributed in Hunan, Guizhou and Sichuan Provinces. The grade is relatively low. Systematic appraisal of unconventional uranium resources has not yet been conducted.

Province	Ore field / basin / deposit	Deposit types	Resources tU, as of 01.01.2019
Jiangxi	Xiangshan orefield	Volcanic-related and granite-related	26 200
	Ganzhou orefield	Volcanic-related and granite-related	28 900
	Taoshan orefield	Granite-related	8 000
Guangdong	Xiazhuang orefield	Granite-related	11 600
	Zhuguangnanbu orefield	Granite-related	19 700
	Heyuanbei deposit	Granite-related	2 300
Hunan	Xiangcaodawan orefield	Granite-related	7 600
Guangxi	Chanziping deposit (Ziyuan site)	Black shales	9 500
Xinjiang	Yili basin	Sandstone	42 700
	Tuha basin	Sandstone	10 100
Inner Mongolia	Erdos basin	Sandstone	80 100
	Erlian basin	Sandstone	52 100
	Tongliao basin	Sandstone	16 500
	Bayingebi basin	Sandstone	7 500
Hebei	Qinglong orefield	Volcanic-related	6 700
Yunnan	Chengzishan deposit (Tengchong site)	Sandstone	4 300
Shaanxi	Lantian deposit	Granite-related	1 200
Gansu	Guangshigou deposit (Longshoushan site)	Intrusive	1 450
Zhejiang	Dachayuan deposit (Dazhou site)	Volcanic-related	2 100
Liaoning	Lianshanguan deposit (Benxi site)	Metasomatite	350
Sichuan	Zhajiang deposit (Ruoergai site)	Black shales	5 100
Total (in situ)			344 000

Uranium production

Historical review

The nearly 60-year history of China's natural uranium production includes a boom in the first two decades and a decline from the late 1980s to the 1990s. In the early 2000s, there was a surge in activity, driven principally by the ambitious new nuclear power plant construction programme announced by the Chinese government and the increase in uranium spot price at that time. As a result, uranium production was reinvigorated.

As domestic uranium demand is projected to increase rapidly in the coming decades, China accelerated the pace of domestic uranium mining to ensure uranium supply. Several existing uranium production centres, such as Fuzhou and Yining, expanded their capacity to achieve both stable and increased production. Additionally, to promote uranium production, the development of other new uranium production centres based on uranium deposits with reliable reserves and favourable technological/economic feasibilities, such as the Tongliao production centre, was also accelerated. Finally, to construct new uranium production centres in the future, a series of pilot tests and feasibility studies were carried out on some newly discovered ISL-amenable sandstone uranium deposits with abundant reserves, such as the sandstone-type uranium deposits in the Erdos and Erlian Basins.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5	Centre #6
Name of production centre	Fuzhou	Chongyi	Yining	Lantian	Shaoguan	Tongliao
Production centre classification	Existing	Idled	Existing	Idled	Existing	Existing
Date of first production	1966	1979	1993	1993	1967	2015
Source of ore:						
Deposit name(s)				Lantian		
Deposit type(s)	Volcanic	Granite	Sandstone	Granite	Granite	Sandstone
Resources (tU)	NA	NA	NA	NA	NA	NA
Grade (% U)	NA	NA	NA	NA	NA	NA
Mining operation:						
Type (OP/UG/ISL)	UG	UG	ISL	UG	UG	ISL
Size (tonnes ore/day)	1 000	600	NA	300	650	NA
Average mining recovery (%)	92	90	NA	80	90	NA
Processing plant:						
Acid/alkaline	Acid	Acid	Acid	Acid	Acid	CO_2+O_2*
Type (IX/SX)	IX	IX	IX	IX	IX	IX
Size (tonnes ore/day); for ISL (l/day or l/h)	1 000	600	NA	NA	NA	NA
Average process recovery (%)	90	84	NA	90	90	NA
Nominal production capacity (tU/year)	350	0	850	0	200	200
Plans for expansion	NA	NA	NA	NA	NA	NA
Other remarks	NA	NA	NA	NA	NA	NA

* Considered a form of alkaline in situ leaching by some countries, as CO_2+O_2 ISL is alkaline at the beginning of the process, then neutral or slightly acidic at the end.

Status of production capability

In response to a sustained decline in uranium prices and to meet the environmental goals announced by the Chinese government, Chinese uranium companies reorganised from 2017 to 2018. First, several underground hardrock uranium mines with depleted uranium resources or with high production costs were either closed or saw production suspended (idled). Second, the mining of ISL sandstone uranium deposits in northern China continued, including the expansion of ISL production capacity in Xinjiang and Inner Mongolia. As a result, a domestic uranium industry focused on production dominated by ISL mining in northern China, supplemented by underground mining in Southern China, has emerged. The overall capacity of uranium production has remained steady after the reorganisation.

Of the seven production centres established in China by 2015, the Fuzhou and Shaoguan production centres are still in operation. Also, the production capacity of the Yining centre in the Xinjiang Autonomous Region (north-west China), and the Tongliao centre in Inner Mongolia (north-east China) were expanded. Production was suspended at the Chongyi production centre in Jiangxi Province (south-east China) and the Lantian centre in Shaanxi Province (north-west China), while the Qinglong production centre in Hebei Province (northeast China) was closed and put into decommissioning. Additional information on these production centres follows:

- The Fuzhou production centre in Jiangxi Province is an underground mine, which exploits Xiangshan volcanic-related type uranium resources through conventional ion-exchange processing.

- The Shaoguan production centre in Guangdong Province is an underground mine, which exploits Xiazhuang and Zhuguang granite-related type uranium resources using an ion-exchange process. The Xiazhuang deposit was closed due to depletion of resources and high production costs; the other deposits are in operation.
- The Yining ISL production centre, located in Yining, Xinjiang Autonomous Region, mainly exploits sandstone-type uranium resources in the Yili and Turpan-Hami Basins using an ion-exchange hydrometallurgical process. Construction of the new Mongqiguer ISL project in this centre has significantly increased production capacity.
- The Tongliao production centre in Inner Mongolia is an ISL mine, which exploits sandstone-type uranium resources in the southern Songliao Basin using an ion-exchange process. The ISL facilities of this centre are being expanded, and production capacity will be increased.
- The Chongyi production centre in Jiangxi Province, an underground mine, mainly exploits the Lujing and Taoshan granite-related type uranium resources with a hydrometallurgical process using heap leaching and ion-exchange. Production was idled at this centre due to depletion of resources and high production costs.
- The Lantian production centre in Shannxi Province is an underground mine that mainly exploits Lantian granite-related type uranium resources with an in-place leaching process. Production was idled due to depletion of resources and high production costs.
- The Qinglong production centre in Hebei Province is an underground mine that mainly exploited Qinglong volcanic-related type uranium resources with heap leaching and solvent extraction. This centre was closed and put into decommissioning due to depletion of resources and high production costs.

Annual uranium production in China during the last five years is assumed to have been maintained at a level of 1 600 tU and is assumed to have remained steady at 1 600 tU in 2021. The share of ISL production exceeds 70% of the total, with the potential to increase in future to eventually replace production from underground mines with higher production costs.

Regarding overseas uranium development, the CNNC and CGN have been involved in several uranium mining projects in Namibia, Kazakhstan and Niger. The CNNC in 2014 bought a 25% equity stake from Paladin Energy in its flagship Langer Heinrich uranium mine that has been on care and maintenance since September 2018. Production was also idled at the CNNC Azelik uranium project in Niger at the end of 2014 and it remains on care and maintenance. On 26 November 2018, the CNNC signed a share-sale agreement with Rio Tinto and bought a 68.62% equity stake of the Rössing uranium mine in Namibia. Rössing produced 2 072 tU in 2019, 2 109 tU in 2020 and 2 444 tU in 2021. The Husab project in Namibia, which is 90% owned by the CGN, produced 3 692 tU in 2019, 3 300 in 2020 and 3 309 in 2021. In Kazakhstan, the Semizbay and Irkol mines held by CGN-Kazatomprom produced 960 tU in 2019, declining to 753 tU in 2020 and recovering to 962 tU in 2021. In July 2021, the CGN aquired a 49% stake in the JV Ortalyk which owns and operates the Central Mynkuduk mine, which produced 1 579 tU in 2021, and the Zhalpak mine, which is under construction.

Ownership structure of the uranium industry

The uranium industry is owned by state-run enterprises in China. Six production centres (Fuzhou, Shaoguan, Chongyi, Yining, Lantian, and Qinglong) are sole proprietorship enterprises owned by the CNNC. The Tongliao production centre is a joint venture owned by the CNNC and the CNPC.

The overseas uranium exploration and development activities are undertaken by the CNNC and CGN. The CNNC owns the largest share of the Rössing uranium mine in Namibia and holds an equity stake in the Langer Heinrich uranium mine in Namibia. The CGN owns the largest share of the Husab uranium mine in Namibia. In Kazakhstan, CGN also holds a 49% equity stake in the JV Semizbay and a 49% stake in the JV Ortalyk.

Employment in the uranium industry

In 2017 and 2018, the industrial restructuring of domestic uranium production continued in China. Production at most of the underground uranium production centres of Southern China with relatively high costs was idled or closed, resulting in a significant reduction in the number of employees. ISL uranium production centres that have been expanded in northern China are highly automated, with no requirement for increased employment. Consequently, employment in China's uranium production sector has decreased considerably. However, without publicly available information on the number of employees for 2019 and 2020, employment in the Chinese uranium industry has been assumed to have remained at the 2018 level.

Future production centres

Industrial ISL tests are being carried out in some parts of the Erdos and Erlian sandstone-type uranium deposits in Inner Mongolia. Encouraging results have been achieved from the ISL tests, which may render those deposits the principal uranium production centres in China. Once the uranium market rebounds, the suspended uranium production centres are expected to be put into operation again.

Uranium requirements

As of 1 January 2021, the total installed capacity of the 50 nuclear power plants in operation in mainland China was 47.5 GWe. Annual uranium requirements amount to about 9 500 tU. Nuclear power generated a total of 344.7 TWh of electricity in 2020, accounting for 4.9% of total generated electricity. Furthermore, an additional 17 nuclear power plants with capacity of 17.4 GWe were under construction in China as of July 2022.

During the 13th Five-Year Plan period, the Chinese government promoted nuclear power construction, especially in coastal areas. It also promoted the principle of developing in a clean, low-carbon and eco-friendly manner, as well as ensuring safety. It was projected that the total installed capacity of nuclear power plants would reach between 50 GWe and 52 GWe by the end of 2020. Based on preliminary projections for the reference scenario, uranium requirements will rise to 22 600 tU in 2030, and to 43 400 tU in 2040.

Supply and procurement strategy

To meet the demand of nuclear power plants planned within the development programme approved by the government, the policy "Facing Two Markets and Using Two Kinds of Resources" was adopted. Uranium supply will be guaranteed through a combination of domestic production, development of non-domestic resources and international trade. As a supplement and balance to domestic production and supply, international trade will ensure a stable supply with reasonable prices on both the spot and future markets.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The Chinese government has increased its attention to uranium supply, with an emphasis on safe, economic and diverse supply sources to ensure reliability. Adequate commercial stocks are also required. The government has taken several measures to support the exploration and development of uranium resources, such as stable investment for domestic exploration; allowing non-government organisations to engage in uranium exploration activities; reviewing the restrictions associated with regulation of domestic production; as well as promoting investment in overseas uranium resources and the establishment of overseas production centres.

Uranium prices

The uranium price has been gradually aligned with the international market price in order to follow the global trend of uranium prices. Accordingly, uranium is priced in China following the fluctuations of the international market.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	0	5 800	55 090	59 810
Open-pit mining (OP)	0	0	0	0
In situ leaching acid	17 600	34 900	52 300	52 300
In situ leaching with CO_2+O_2*	27 800	38 360	42 360	42 360
Co-product and by-product	0	0	0	0
Total	45 400	79 060	149 750	154 470

* Considered a form of alkaline in situ leaching by some countries, as CO_2+O_2 ISL is alkaline at the beginning of the process, then neutral or slightly acidic at the end.

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	0	5 800	55 090	59 810
In situ leaching acid	17 600	34 900	52 300	52 300
In situ leaching with CO_2+O_2*	27 800	38 360	42 360	42 360
Total	45 400	79 060	149 750	154 470

* Considered a form of alkaline in situ leaching by some countries, as CO_2+O_2 ISL is alkaline at the beginning of the process, then neutral or slightly acidic at the end.

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	0	11 300	58 500	81 490
In situ leaching CO_2+O_2*	49 500	85 650	90 350	90 350
In situ leaching acid	9 700	12 100	13 190	13 190
Total	59 200	109 050	162 040	185 030

* Considered a form of alkaline in situ leaching by some countries, as CO_2+O_2 ISL is alkaline at the beginning of the process, then neutral or slightly acidic at the end.

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	0	11 300	58 500	81 490
In situ leaching with CO_2+O_2*	49 500	85 650	90 350	90 350
In situ leaching acid	9 700	12 100	13 190	13 190
Total	59 200	109 050	162 040	185 030

* Considered a form of alkaline in situ leaching by some countries, as CO_2+O_2 ISL is alkaline at the beginning of the process, then neutral or slightly acidic at the end.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	NA	1 150	1 150	NA	1 150
Granite-related	NA	200	200	NA	200
Volcanic-related	NA	250	250	NA	250
Total	46 299	1 600	1 600	49 499	1 600

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	NA	450	450	NA	450
In-place leaching*	NA	0	0	NA	0
In situ leaching	NA	1 150	1 150	NA	1 150
Heap leaching**	NA	NA	NA	NA	NA
Total	46 299	1 600	1 600	49 499	1 600

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining since it is used in conjunction with them.

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Underground mining	NA	450	450	NA	450
In situ leaching	NA	1 150	1 150	NA	1 150
Total	46 299	1 600	1 600	49 499	1 600

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
1 600	100	0	0	0	0	0	0	1 600	100

Uranium industry employment at existing production centres

(person-years)

	2019	2020	2021 (expected)
Total employment related to existing production centres	2 290	2 300	2 300
Employment directly related to uranium production	1 490	1 500	1 500

Czech Republic

Uranium exploration and mine development

Historical review

Uranium exploration in former Czechoslovakia began in 1946 and rapidly developed into a large-scale programme in support of the country's uranium mining industry. A systematic exploration programme including geological, geophysical, and geochemical surveys and related research was carried out to assess the uranium potential of the country. Areas with identified potential were explored in detail using drilling and underground exploration methods.

Exploration continued systematically until 1989, with annual exploration expenditures in the range of CZK 210-430 million (USD 10-20 million) and an annual drilling effort in the range of 70-120 km. Exploration was traditionally centred around vein deposits located in metamorphic complexes (Jáchymov, Horní Slavkov, Príbram, Zadní Chodov, Rozná, Olsí and other deposits), granitoids of the Bohemian massif (Vítkov deposit) and around the sandstone-hosted deposits in northern and north-western Bohemia (Hamr, Stráz, Brevniste, Osecná-Kotel, Hvezdov, Vnitrosudetská Pánev, Hájek and other deposits).

In 1989, the decision was made to reduce all uranium-related activities. Expenditures decreased to about CZK 150 million (USD 7 million) in 1990 and have not reached that level since. No field exploration has been carried out since the beginning of 1994.

Recent and ongoing uranium exploration and mine development activities

Recent uranium exploration activities have been focused on the conservation and processing of previously collected exploration data from Czech uranium deposits. Advance processing of the exploration data and building the exploration database will continue in the coming years.

In the years 2019-2020, the geological survey data were processed (analysis and evaluation of rock samples, geological documentation, developing a feasibility study and final reports, and archiving). Exploration expenditures were CZK 4.4 million in 2019, CZK 6.8 million in 2020, and were expected to be CZK 6.2 million in 2021. That is approximately equivalent to USD 197 000, USD 284 000, and USD 289 000, respectively.

Uranium resources

Historically, most of the known uranium resources of the Czech Republic occurred in 23 deposits, of which 20 have been mined out or closed. Of the three remaining deposits, only Rozná and Stráz were mined. Resources at the Stráz deposit are, however, limited due to the remediation process and resources at the Rozná deposit have already reached the limits of economic profitability. Other deposits (the Osecná-Kotel part of the Stráz bloc and Brzkov) have resources that are not mineable because of environmental concerns.

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2021, total identified recoverable conventional resources (reasonably assured resources and inferred resources) amounted to 119 107 tU. There was a decrease of 62 tU from previous estimates as of 1 January 2019, due to the mining and re-evaluation of uranium resources at the relevant deposits.

In detail, the reasonably assured resources recoverable at a cost of <USD 130/kgU amounted to 804 tU. These are recoverable resources in existing production centres at the Stráz deposits. Reasonably assured resources recoverable at a cost of <USD 260/kgU amounted to 50 848 tU, a decrease of 62 tU compared to the estimates as of 1 January 2019. The remaining resources of the Rozná deposit, in the amount of 187 tU, are also included in this cost category.

Inferred resources recoverable at a cost of <USD 260/kgU amounted to 68 259 tU and are unchanged compared to estimates as of 1 January 2019. These high-cost resources are located in the Rozná deposit and especially in the Stráz bloc (the Stráz, Hamr, Osecná-Kotel, and Brevniste deposits), but remain unmined due to environmental concerns.

Undiscovered conventional resources (prognosticated and speculative resources)

As of 1 January 2021, total undiscovered conventional resources (prognosticated resources and speculative resources) amounted to 239 915 tU. Prognosticated resources at a cost <USD 260/kgU amounted to 222 915 tU and are unchanged from previous estimates as of 1 January 2019. These resources occur mainly (98%) in the sandstone deposits of the Northern Bohemian Cretaceous Basin (Stráz block, Tlustec block and Hermanky deposits) and to a lesser extent (2%) in the metamorphic complex of Western Moravia (Rozná and Brzkov deposits).

Speculative resources at a cost around or greater than USD 260/kgU are estimated to amount to 17 000 tU and are reported in the unassigned cost category. Since these resources occur in Northern Bohemian Cretaceous sandstone deposits in a groundwater source protection zone, further exploration and evaluation are not permitted.

Uranium production

Historical review

The history of uranium mining in the Czech Republic dates to the early 19th century. Uranium ores have been mined for the glass, ceramic and ink industry in Jáchymov since 1858.

Industrial development of uranium production in former Czechoslovakia began in 1946. Between 1946 and the dissolution of the former Soviet Union in 1991, all uranium produced in former Czechoslovakia was exported to the former Soviet Union.

The first production came from the Jáchymov and Horní Slavkov mines, which completed operations in the mid-1960s. Príbram, the main vein deposit, operated from 1950 to 1991. The Hamr and Stráz production centres, supplied by sandstone deposits, started operation in 1967. Peak annual national production of about 3 000 tU was reached around 1960 and production remained between 2 500 and 3 000 tU/yr from 1960 until 1989/1990 and declined thereafter. A cumulative total of 112 229 tU was produced in the Czech Republic during the period 1946-2020, of which about 84% was produced by underground and open-pit mining methods and the remainder was recovered by in situ leaching.

Status of production facilities, production capability, recent and ongoing activities and other issues

Formally, two production centres remain in the Czech Republic. One is an ore processing plant (Rozná) in the Dolní Rozínka uranium production centre (Western Moravia) and the second is a chemical mining centre in Stráz pod Ralskem (Northern Bohemia). Both the Dolní Rozínka and Stráz pod Ralskem production centres are wholly operated by the state-owned enterprise DIAMO.

The Dolní Rozínka centre (Rozná processing plant) produced 0 tU in 2018, 1 tU in 2019 and 1 tU in 2020 from water treatment only. Because the mining of uranium resources located in the Rozná mine became unprofitable, it was decided to terminate the operation and start decommissioning the mine as of 1 January 2017. The underground of the mine is gradually being flooded. The production centre (Rozná mill) is maintained in operation for the uranium extraction from mine water treatment and for the reprocessing of waste dumps. Expected uranium production at Dolní Rozínka production centre in 2021 is 4 tU.

At the Stráz pod Ralskem chemical mining centre (Stráz sandstone deposit, with resources of 804 tU recoverable at cost <USD 130/kgU), the former acid in situ leaching (~180 m underground) production centre, produced 29 tU in 2018, 36 tU in 2019 and 28 tU in 2020. Uranium produced at this centre is a product of environmental remediation activities that began in 1996. Production capability during remediation (without acid) has decreased because of lower uranium concentration in solutions. Production in 2021 is expected to amount to 27 tU. In the long term, a gradual decline in production is expected.

Uranium is also obtained from mine water treatment (at existing and former facilities), with a total recovery of 5 tU expected in 2021 (not including U recovery from in situ leaching [ISL] mining restoration activities).

Ownership structure of the uranium industry

All uranium activities, including exploration, production and related environmental activities, are being carried out by the state-owned enterprise DIAMO, a mining and environmental engineering company based in Stráz pod Ralskem.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #2
Name of production centre	Dolní Rozínka	Stráz pod Ralskem
Production centre classification	Existing	Existing
Date of first production	1957	1967
Source of ore:		
Deposit name(s)	Rozná	Stráz
Deposit type(s)	Metamorphite	Sandstone
Recoverable resources (tU)	187	804
Grade (% U)	0.171	0.030
Mining operation:		
Type (OP/UG/ISL)	–	ISL
Size (tonnes ore/day)	–	-
Average mining recovery (%)	–	60 (estimated)
Processing plant:		
Acid/alkaline	Alkaline	Acid
Type (IX/SX)	IX	IX
Size (tonnes ore/day) For ISL (kilolitre/day)	530 –	– 10 000
Average process recovery (%)	90 (estimated)	60 (estimated)
Nominal production capacity (tU/year)	300	100
Plans for expansion	No	No
Other remarks	Since 2018, only the processing plant has been in operation; the Rozná mine is being decommissioned	Since 1996, production occurs through the remediation process

Employment in the uranium industry

Total employment in the Czech uranium production centres amounted to 1 556 jobs in 2019 and 1 546 in 2020 (i.e. employment related to the production including head office, auxiliary divisions, mining emergency services).

Employment directly related to uranium production at Dolní Rozínka and Stráz pod Ralskem centres was 806 in 2019 and 793 in 2020; however, some uranium production is associated with remediation.

Future production centres

No other production centres are committed or planned in the near future. A potential production centre at the Brzkov deposit is a possibility to be discussed in the distant future.

Secondary resources of uranium

Production and/or use of mixed oxide fuels

The Czech power utility CEZ, a.s. is the sole owner and operator of nuclear power plants in the Czech Republic and does not use MOX fuels in its reactors.

Production and/or use of re-enriched tails

CEZ does not use re-enriched tails in its reactors.

Production and/or use of reprocessed uranium

CEZ does not use reprocessed U in its reactors.

Environmental activities and socio-cultural issues

Managing environmental activities and social issues takes place under the government programme accompanying the down-sizing of the Czech uranium mining industry. These activities began in 1989. Although this programme was formally terminated in 2009, extensive environmental remediation projects and some associated social issues continue to be addressed with the help of national and EU funding.

This programme has been aimed at gradually decreasing employment to match declining uranium production and at developing alternative (mainly environmental) projects to address social issues.

In general, the environmental activities include project preparation, environmental impact assessments, decommissioning, tailing impoundments and waste rock management, site rehabilitation and maintenance, water treatment and long-term monitoring.

The key environmental remediation projects are as follows:

- Remediation of the after-effects of the ISL used in Stráz pod Ralskem that impacted a total of 266 million m^3 groundwater and an enclosure of 600 ha surface area.
- Rehabilitation of the tailing impoundments in Mydlovary, Príbram, Stráz pod Ralskem and Rozná (a total of 18 ponds with a total area of 593.7 ha).
- Rehabilitation (including reprocessing) of the waste rock dumps in Príbram, Hamr, Rozná, Western Bohemia and other sites (a total of 368 dumps with a capacity 47.92 million m^3).

- Mine water treatment from former uranium facilities in Príbram, Stráz, Horní Slavkov, Olsí and others, amounting to a total of approximately 12 million m³/year, which results in the recovery of about 5 tU annually.

Post remediation monitoring and long-term stewardship of the mining legacy sites.

Most of the environmental expenses (about 85%) are funded by the state budget, with the remainder financed by the EU (9-12%) and DIAMO (3-6%). Since 1989, CZK 53 053 million (about USD 2 490 million) were spent on the environmental remediation projects, i.e. excluding social programmes and social security. The projects, which are due to continue until approximately 2040, are expected to have a total cost of more than CZK 60 000 million (about USD 2 817 million).

The social part of the programme (obligatory spending, compensation, damages, and rent) is financed entirely by the state budget.

Expenditures related to environmental activities and social issues

(CZK millions)

	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Uranium environmental remediation	49 383	1 911	1 759	53 053	1 871
Social programme and social security	10 267	118	100	10 485	88
Total	59 650	2029	1 859	63 538	1 959

Uranium requirements

There are two nuclear power plants with a total of six units in operation in the Czech Republic: the older Dukovany Nuclear Power Plant with four VVER-440 reactors, which have been uprated to 510 MWe (gross) in the 2009-2019 period, and the younger Temelin Nuclear Power Plant with two VVER-1000 reactors, which have been uprated to 1 080 MWe (gross). The sole owner and operator of these nuclear power plants is the Czech power company CEZ, a.s.

There is a general consensus that it will be necessary to build new units in the Czech Republic, and a goal has been set to commission the first new unit by 2040 with others to follow. CEZ is focused on long-term operation projects of both current nuclear power plants, and preparation work for new builds at both sites. Negotiations between the Czech government and CEZ concerning the construction of new units are ongoing; however, it has already been agreed that the first unit with an output of up to 1 200 MWe (gross) shall be built at the Dukovany site by a subsidiary called Elektrarna Dukovany II.

Total uranium requirements of both nuclear power plants have been averaging 675 tU/year on a long-term basis, though future annual requirements will vary depending on outage planning due to the ongoing projects to implement longer fuel cycles (16-month at Dukovany and 18-month at Temelin).

Supply and procurement strategy

CEZ has obtained uranium on the basis of medium- and long-term contracts, as well as taking advantage of the current low spot market prices. Some uranium was purchased in world markets, and some was purchased in the form of fabricated fuel, delivered from the Russian fabricator TVEL as a package.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The programme to wind down the Czech uranium industry from the end of the 1980s has already been formally terminated. An extensive programme for the environmental remediation of former uranium production facilities continues.

The "State Energy Policy of the Czech Republic" (approved by Government Decree No. 362/2015 Coll.) assumes a balanced energy mix and a share of up to 50% of nuclear energy in total domestic electricity production after 2040.

To provide the necessary raw material resources, the government adopted the "Raw Materials Policy in the Field of Mineral Materials and their Resources" (updated by Government Decree No. 441/2017 Coll.), which ranks uranium among the critical super strategic raw materials in line with the European "Raw Materials Initiative". This document considers the priority use of domestic uranium resources if it is economically and environmentally feasible.

According to the government's "Concept of the Raw Materials and Energy Security of the Czech Republic", a feasibility study of early development at Brzkov uranium deposits was completed in 2014, as well as new technological possibilities for uranium mining that strictly respect environmental concerns.

The government of the Czech Republic approved mining activities by DIAMO at the Brzkov deposit (Vysocina region); however, there has been significant opposition by local municipalities and strong public resistance to the resumption of uranium mining in the area.

Uranium stocks

The Czech power company CEZ maintains uranium stocks at the level of about two and a half years of forward reactor consumption in all forms of processed uranium. A substantial portion of these stocks is in the form of fabricated fuel stored at the nuclear power plant sites.

Uranium prices

Uranium prices are not available as they are commercially confidential. In general, uranium prices in supply contracts incorporate price indicators from the world market according to agreed formulas.

Uranium exploration and development expenditures and drilling effort – domestic

(CZK millions)

	2018	2019	2020	2021 (expected)
Private* exploration expenditures	0.0	0.0	0.0	0.0
Government exploration expenditures	0.2	4.4	6.8	6.2
Private* development expenditures	0.0	0.0	0.0	0.0
Government development expenditures	0.0	0.0	0.0	0.0
Total expenditures	0.2	4.4	6.8	6.2

* Non-government.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	0	1 665	90
In situ leaching acid	0	0	804	49 183	60
Total	0	0	804	50 848	

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	0	1 665	90
In situ leaching acid	0	0	804	49 183	60
Total	0	0	804	50 848	

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	804	49 183
Metamorphite	0	0	0	1 665
Total	0	0	804	50 848

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	0	459	90
In situ leaching acid	0	0	0	67 800	60
Total	0	0	0	68 259	

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	0	459	90
In situ leaching acid	0	0	0	67 800	60
Total	0	0	0	68 259	

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	0	67 800
Metamorphite	0	0	0	459
Total	0	0	0	68 259

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	222 915

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	17 000

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Underground mining*	94 455	6	6	94 467	9
In situ leaching	17 698	36	28	17 762	27
Total	112 153	42	34	112 229	36

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	91 710	0	0	91 710	0
In-place leaching*	3	0	0	3	0
Heap leaching**	125	0	0	125	0
In situ leaching	17 698	36	28	17 762	27
Other methods***	2 617	6	6	2 629	9
Total	112 153	42	34	112 229	36

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

*** Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	27 934	36	28	27 998	27
Granite-related*	60 893	5	5	60 903	5
Metamorphite	23 305	1	1	23 307	4
Metasomatite	0	0	0	0	0
Lignite and coal	1	0	0	1	0
Other/unspecified	20	0	0	20	0
Total	112 153	42	34	112 229	36

* Includes uranium recovered from mine water treatment; 5 tU in 2018, 5 tU in 2019, 5 tU in 2020 and 5 tU expected in 2021.

From 1945 to 1985, historical uranium production by deposit type was derived from the statement of production centres (more than one type of deposit was processed at the only production centre).

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
34	100	0	0	0	0	0	0	34	100

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres	1 557	1 556	1 546	1 550
Employment directly related to uranium production	786	806	793	779

Mid-term production projection (tonnes U/year)

2021	2022	2025	2030	2035	2040
36	40	50	50	30	20

Mid-term production capability (tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	50	50	0	0	50	50

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	30	30	0	0	20	20

Net nuclear electricity generation (TWh net)

	2019	2020
Nuclear electricity generated (TWh net)	28.6	30.1

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
3 940	3 940	3 940	3 960	3 940	3 980	3 940	3 980	3 940	5 100

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
652	594	530	920	530	920	530	920	530	920

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	0	0	0	0	0
Producer	>200	0	0	0	>200
Utility	NA	NA	0	0	NA
Total	NA	NA	0	0	NA

Denmark/Greenland

Uranium exploration and mine development

Historical review

Uranium exploration and assessment activities have been performed across Greenland, most recently in the north. The earliest exploration for uranium was carried out using Geiger counters over selected areas of southern Greenland from 1955 to 1956, leading to the discovery of radiation anomalies associated with the Kvanefjeld deposit, a large low-grade U-Th-REE deposit associated with the Mesoproterozoic Ilímaussaq layered alkaline intrusive rock complex. In 1973, Denmark, including Greenland, joined the European Economic Community when uranium exploration was encouraged in member states to secure the community's uranium resources.

Since the Kvanefjeld deposit in southern Greenland was discovered in the mid-1950s, exploration of the area continued through 1984 with various geophysical and geochemical surveys, drilling, detailed geological mapping, and test mining and assaying work. Resources at the time were estimated at 27 000 tU, with 16 000 tU in the "additional resources" category. Additional activities in southern Greenland included a regional exploration programme from 1979 to 1986 involving airborne gamma spectrometry, drainage geochemistry and geological studies. Three prospects were found: 1) uraninite in mineralised fractures and veins; 2) uranium-rich pyrochlore mineralisation in alkaline rocks and; 3) uraninite in hydrothermally mineralised metasediments. These prospects at the time were believed to represent 60 000 tU in the "speculative resources" category.

Between 1972 and 1977, a reconnaissance uranium exploration programme was conducted in eastern Greenland involving airborne gamma spectrometry, drainage geochemistry, ground scintillometry and geological studies, but no major discoveries were made. Additional reconnaissance in western Greenland with airborne gamma spectrometry and follow-up groundwork was performed, also without a major discovery.

Following a decision in 1985 by the Danish government to exclude nuclear power from its energy sources, a policy was introduced in 1988 to ban the mining of uranium and other radioactive elements in Greenland. Exploration activities continued, however, and in 1995 a stream sediment survey was undertaken that included analysis for uranium and thorium, as well as scintillometer readings covering 7 000 km^2 in northwest Greenland, but no prospects were found. In 2009, the "Self-Government Act" passed by the Danish Parliament granted Greenland control over its natural resources, and in 2013, the Greenland government lifted the ban on mining of uranium and other radioactive elements, generating renewed interest in evaluating the potential of Greenland's uranium resources.

In November 2016, an assessment of the uranium potential in Greenland was conducted jointly by the Geological Survey of Denmark and Greenland and the Ministry of Mineral Resources, Government of Greenland. Three uranium deposit types were considered: intrusive, sandstone-hosted and unconformity-related. The assessment concluded that intrusive and unconformity-related deposits have the highest potential for economic concentrations of uranium, and that southern Greenland has the highest potential for hosting undiscovered deposits.

Recent and ongoing uranium exploration and mine development activities

Since 2007, Greenland Minerals Ltd (GML), a publicly listed company, had conducted exploration activities for REE-U-Zn mineralisation in the Kvanefjeld area, in southern Greenland, including drilling of 57 710 m of core. The business concept encompassed uranium and zinc by-products in addition to the main products of REE. A mining/exploitation licence application was submitted in July 2019, including updated environmental and social impact assessments (EIA and SIA) together with a navigational safety investigation study (NSS). It was expected that uranium would be recovered from leach solutions using industry standard solvent extraction to produce approximately 500 tonnes of U_3O_8 (425 tU) per year. The consultation period had started in December 2020, and responses received to the EIA and SIA during the consultation period were to be summarised in the form of a white paper by the company. Final EIA and SIA reports were to be prepared with amendments according to the consultation comments and responses. Afterwards, the Government of Greenland was to decide on whether to accept the final EIA and SIA reports and white papers, and whether or not to grant an exploitation licence. An April 2021 election in Greenland, however, led to a change in government that passed a new law prohibiting exploration and exploitation of uranium as of December 2021. Passage of this new law led GML to request arbitration proceedings with the governments of Greenland and Denmark concerning the impact of new legislation on its exploration licence for the Kvanefjeld REE, zinc and uranium project under development in southern Greenland.

As of 1 January 2021, uranium exploration and development expenditures and drilling statistics were not available for 2020 and 2021.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

The Ilímaussaq igneous complex of southern Greenland hosts the REE-U-Zn-F deposit referred to as Kvanefjeld. It is a high-tonnage, low-grade uranium-enriched layered intrusive deposit, with concentrations of around 300 ppm U. Uranium is planned to be mined as a by-product from a proposed open-pit mine. GML estimates that uranium will account for 5% of the revenue. Kvanefjeld is the only uranium deposit or occurrence in Greenland with reasonably assured uranium resources. The supply cost for uranium will be very low, as the majority of the costs will be borne by the production of the REE, the primary resource (Kvanefjeld is considered to be one of the largest REE deposits in the world). GML has reported a uranium specific supply cost of approximately USD 13/kgU (USD 5/lb U_3O_8), which is incremental to the cost of the REE production. The total identified in situ reasonably assured conventional mineral resource inventory for Kvanefjeld is 102 820 tU. Additional in situ inferred mineral resources of 338 Mt ore exist in the Zone Sørensen and Zone 3, related to Kvanefjeld, equivalent to 125 143 tU. Recoverable uranium resources are calculated using the established and pilot plant tested flowsheet of approximately 50%.

Undiscovered conventional resources (prognosticated and speculative resources)

Several uranium occurrences are known in Greenland: seven in southern Greenland, three in western Greenland and three in eastern Greenland. These include: (1) large, low-grade magmatic deposits; (2) small syn- to epigenetic pyrochlore mineralisation related to alkaline syenite and carbonatite; and (3) small, high-grade epigenetic uraninite mineralisation hosted in fracture zones. Most of these are showings and prospects, with Kvanefjeld the only one with a JORC-compliant reserve estimate. An evaluation of the potential for uranium deposits in Greenland is available at: https://eng.geus.dk/products-services-facilities/publications/minerals-in-greenland/geology-and-ore/geology-and-ore-28.

Unconventional resources and other materials

Unknown.

Uranium production

Historical review

No uranium has been produced in Greenland. However, 4 500 tonnes of ore were transported to the Risø National Laboratory, Denmark, for test work during the 1980s. Another 30 tonnes of ore were sent in 2014 to Outokumpu, Finland, where a pilot plant operation was conducted through the FP7 EURARE project.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Greenland is part of the Danish Realm. Greenland enjoys autonomous authority in domestic affairs while Denmark remains constitutionally responsible for foreign affairs, defence and security. In 2009, the Act on Greenland Self-Government granted Greenland authority over its natural resources (Mineral Resources Act 2009). The Ministry of Mineral Resources and Labour (MMRL) is responsible for strategy and policymaking, legal issues, licence assessment, approvals and inspections, and marketing of mineral resources in Greenland. The Ministry of Industry, Energy and Research (MIER) is responsible for trade and export of mineral resources.

On 24 October 2013, Greenland's Parliament, Inatsisartut, lifted a decades-long moratorium on mining radioactive elements, which opened the way for potential exploration of uranium and thorium.

Denmark and Greenland signed in January 2016 an agreement concerning the special foreign, defence and security policy issues related to the possible future mining and export of uranium in Greenland. While Denmark is responsible for non-proliferation matters in Greenland, especially safeguards, security and dual-use exports, the agreement established a framework for a shared approach to ensure compliance with Denmark's international non-proliferation obligations. The agreement underlines the joint Danish and Greenlandic commitment to observe the highest international standards compared with other uranium supplier states.

The agreement also served as a basis for the new Danish legislation for Greenland on safeguards and export controls, including making exports of nuclear material from Greenland subject to nuclear co-operation agreements to provide assurances that they are properly protected and used for peaceful purposes. The Act no. 616 on export controls for Greenland and Act no. 621 on safeguards for Greenland were passed on 8 June 2016. The Executive Order on safeguard obligations for the peaceful use of nuclear material in Greenland was published on 10 July 2019.

As part of the agreement concerning the special foreign, defence and security policy issues related to the possible future mining and export of uranium in Greenland, the territorial restrictions regarding six nuclear conventions for Greenland are also in the process of being lifted. In 2019, the territorial restrictions for five of these nuclear conventions were lifted. The conventions are:

- The International Convention for the Suppression of Acts of Nuclear Terrorism;
- The Convention on Assistance in Case of a Nuclear Accident or Radiological Emergency;
- The Convention on Nuclear Safety, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management;
- The 2005 Amendment to the Convention on the Physical Protection of Nuclear Material;
- The International Labour Organisation Radiation Protection Convention (No. 115).

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Co-product and by-product	0	0	0	102 820	50
Total	0	0	0	102 820	

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	0	102 820	50
Total	0	0	0	102 820	

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Intrusive	0	0	0	102 820
Total	0	0	0	102 820

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Co-product and by-product	0	0	0	125 143	50
Total	0	0	0	125 143	

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	125 143	50
Total	0	0	0	125 143	

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Intrusive	0	0	0	125 143
Total	0	0	0	125 143

Ecuador

Uranium exploration and mine development

Historical review

Uranium exploration in Ecuador began in the mid-1960s with the establishment of the Prospecting Department of the National Polytechnic School, which oversaw the first investigations for uranium and radioactive mineral occurrences in the country. During that period, the Ecuadorian Atomic Energy Commission (CEEA) was attached to the National Polytechnic School.

Between 1966 and 1967, the CEEA in co-operation with the International Atomic Energy Agency (IAEA; Dr James Cameron) outlined the first radioactive minerals research plan, leading to the discovery and evaluation of several radiometric anomalies between 1968 and 1970 using vehicle-borne gamma surveys. The areas investigated in the south of Ecuador in the late 1970s included Alamor, Sabanilla, Changuarhuayco, Zapotillo, Paletillas and Puyango. During the 1975-1978 period, geochemical surveys were carried out in the provinces of Azuay, Loja and Zamora Chinchipe, as well as further radiometric surveys around the Quijos river region in Napo province.

By the end of the 1970s, more than 300 radioactive anomalies had been identified as a result of 17 300 km^2 of airborne radiometric surveys in the areas of Manabí, Guayas and Cuenca, 17 000 km^2 of car-borne gamma surveys in the Cordillera, and geochemical surveys spanning 8 200 km^2 in the north, centre and south of the country.

Between 1982 and 1984, the CEEA, being responsible for uranium prospecting activities, carried out exploration in co-operation with the IAEA and the United Nations Development Program (UNDP). The areas studied included the Western and Eastern Cordilleran regions and the southwest of Ecuador. Radiometric surveys and geochemical studies of active stream sediments led to the detection of numerous anomalies. The most promising of these anomalies was found in the Puyango area (10 km^2), where the CEEA continued fieldwork that included 600 m of exploration drilling in 4 holes. In the 1990s, CEEA exploration programmes were suspended.

In 2008, the CEEA was merged with the Ministry of Electricity and Renewable Energy, taking the name of Undersecretariat of Nuclear Control, Investigations and Applications (SCIAN), later renamed as the Undersecretariat of Control and Nuclear Applications (SCAN). That same year, the "Program for the Development of Uranium Resources of Ecuador" was established. The short- and medium-term exploration plan included proposals for a new structure and organisation to take charge of developing work programmes, updating equipment and setting up the necessary infrastructure, instruments, and tools (laboratories, petrographic and mineralogical studies, technical archive on uranium prospecting in Ecuador, etc.) for uranium exploration and geological research programmes. The priority was to summarise all research data from the last decades and to update the regional and geological contexts of uranium deposits in Ecuador. This programme recommended taking into consideration the following aspects: 1) regional airborne gamma-ray spectrometry surveys; 2) ground gamma-ray spectrometry surveys in the Eastern and Western Cordilleras; 3) detailed prospecting in seven anomaly clusters; 4) uranium exploration at the "El Limo-La Sota" district and the Puyango deposit (this point was not implemented); and 5) developing a uranium favourability, exploration and resources profile of Ecuador. This was originally to be undertaken between 2010 and 2014, but has not yet been implemented.

In 2009, as part of the IAEA Technical Cooperation Project, "Regional Upgrading of Uranium Exploration, Exploitation and Yellowcake Production Techniques Taking Environmental Problems into Account (RLA3010)", an expert mission on "Uranium Exploration in Ecuador" was implemented. Among other activities, the mission included technical evaluation visits to the Puyango deposit and the anomaly area No. 44 in the province of Azuay. The uranium potential of anomaly No. 44 was considered as low after the evaluation visit.

In 2010, a joint company called "Gran Nacional Minera" was created by the governments of Ecuador and Venezuela. Between 2012 and 2017, "Gran Nacional Minera" conducted exploration on the El Reventador (Quijos river region) phosphate mining concession, located in the Sucumbíos province in the north-east of Ecuador. In 2019, after an advanced exploration assessment, the company decided to close this project and to revert mining concession responsibilities to the Ecuadorian state.

Recent and ongoing uranium exploration and mine development activities

Between 2019 and 2021, the Geological and Energy Research Institute (IIGE), assisted by the IAEA through SCIAN´s liaison, updated and reviewed historical information on uranium exploration in Ecuador, with the objective of taking up research carried out years ago by the National Polytechnic School and the CEEA.

Despite these surveys and background research, the Mining Regulatory and Control Agency (ARCOM) has not reported any private or state concessions in its mining portfolio related to uranium exploration in recent years.

In 2020, the Private Technical University of Loja (UTPL) carried out a geochemical survey in the Chirimoyo and Guineo micro-basins in the Puyango area, finding anomalies of V, U and Zn related to black limestones, bituminous limestones and calcareous shales of marine origin. This study confirmed the radiometric anomalies previously identified by the National Polytechnic School and the CEEA in the 1970s and 1980s.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Identified conventional resources have not been declared in the country to date.

Undiscovered conventional resources (prognosticated and speculative resources)

Undiscovered conventional uranium resources have not been assessed in the country to date.

Unconventional resources and other materials

In the Puyango sedimentary deposit (V, Zn, U, Cu, Pb), tabular-shaped uranium mineralisation is hosted by the Early Cretaceous Puyango Unit, which consists of black limestone, bituminous limestone and calcareous sandstone, underlain by the Aptiense Quebrada Los Sábalos Unit composed of silicified sandstones, conglomerates, volcanoclastic sands and very fine sandstones (with fossilised tree trunks). Further south in the Alamor-Lancones basin, the Maastrichtian Cazaderos Formation, consisting of medium grained sandstones, black shales and siltstones, could also host uranium occurrences.

This deposit may be considered as a potential source of uranium, where this metal may be recovered as minor co- or by-product to other metals. However, no assessment of uranium resources and processing technologies has been carried out to date.

Uranium production

Historical review

Ecuador has never produced uranium concentrates.

Status of production facilities, production capability, recent and ongoing activities and other issues

There are currently no prospects for uranium production in the country.

Egypt

Uranium exploration and mine development

Historical review

Uranium exploration activity started in Egypt as early as 1956. Geophysical, radiometric, and geologic exploration resulted in the discovery of many radioactive anomalies distributed across different geological environments in the Eastern Desert and Sinai.

Over the past several years and in several projects, uranium exploration activity resulted in the identification of the most prospective regions in the country. The uranium exploration programme was undertaken by the Egyptian Nuclear Materials Authority (NMA), which is the government body responsible for nuclear raw materials in the country. The NMA discovered uranium mineralisation in the northern part of the Gabal Gattar granite batholith during the 1984-1985 field season. Within the framework of the resource evaluation programme, the first mining test shafts were excavated in 1998 and 1999 in the Sinai and Gabal Gattar prospects, respectively.

Recent and ongoing uranium exploration and mine development activities

From 2016 to 2019, the NMA focused on the exploration of four prospects in the Eastern Desert and South Sinai. These activities involved exploratory trenching and shallow drilling programmes, supported by geophysical and geochemical surveys, to follow-up subsurface extensions of the formations hosting uranium mineralisation.

Granitic rocks are known to have a much higher uranium content than other common rock types, and uranium exploration activities led to the discovery of several uranium anomalies and occurrences within or near the periphery of some granitic plutons in the Eastern Desert of Egypt (e.g. the Gabel Gattar, Gabel EI-Erediya, El Missikat and Um Ara areas). Secondary uranium minerals dominate the mineralogical composition of these deposits. Yellow mineral impregnations are found in fractured and albitised alkali-feldspar granites. The mineralisation occurs as stains along fracture surfaces and as acicular crystals filling cavities.

Uranium anomalies in south-western Sinai are restricted to the early Carboniferous Um Bogma Formation. Uraniferous zones are associated with the lower and middle members of the Um Bogma Formation shales and dolomites.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Abu Zenima project

The early Carboniferous succession of sandstones, claystones and siltstones hosts anomalous zones with secondary uranium mineralisation. The occurrences are found in several locations around Abu Zenima, in the eastern Gulf of Suez. The economic potential has not yet been fully assessed because of difficult drilling conditions. However, some target areas are under development where secondary uranium mineralisation was identified at the surface. Detailed geologic work, diamond drilling and test mine work are being conducted. A 2008 assessment reported in situ inferred resources of about 100 tU, hosted primarily in sandstones and carbonate rocks. Additional investigations from 2016 to 2019 increased in situ inferred resources to 515 tU.

Gabal Gattar project

An elongated granite batholith trending over 40 km, is host to vein-type uranium mineralisation associated with molybdenite, defined in eight uraniferous occurrences. These occurrences are characterised by intense secondary uranium minerals with characteristic yellow to greenish-yellow colours. Nearly all the recorded uranium occurrences are associated with strongly deformed and deeply hematitised zones.

Uranium resources of 2 000 tU of in situ inferred resources were last reported in the 2009 Red Book for Gabal Gattar. In the last two years, the area has been the subject of some subsurface exploration work (deep trenching and shallow drilling) to follow-up prospective subsurface extensions of mineralisation and to correlate with surface occurrences. Thus far, no additional resource estimates have been made.

Undiscovered conventional resources (prognosticated and speculative resources)

Egypt has conducted systematic uranium resource prediction and evaluation with prognosticated resources estimated to be around 13 600 tU, as reported in the following tables. Identified uranium resources increased due to drilling activity and re-evaluation of uranium resources.

Abu Rusheid project

Uranium occurrences are associated with rare earth elements (REE) in the paragneiss and metamorphosed sandstones in the Abu Rusheid project area. However, previous Red Book reports indicate that no speculative uranium resources were identified. Exploration activity in recent years has added an estimated potential of 10 000 tU of in situ prognosticated resources to the Abu Rusheid area. The NMA intends to continue work by undertaking a drilling programme in the coming years to confirm these results.

El Sella project

Additional potential resources may be identified in the El Sella project area, where uranium exploration permits have been held over the past few years. Ongoing exploration is aimed at extending the existing orebody as well as identifying and evaluating new ore bodies, given the potential for additional resources. The area contains an estimated potential for 3 600 tU of in situ prognosticated uranium resources. Follow-up drilling is expected to continue through 2020-2022. With further exploration in uranium prospective areas, more uranium resources are expected to be discovered.

Unconventional resources and other materials

The Egyptian phosphate deposits represent one of the more promising unconventional uranium resources. Estimates of these phosphate ores reach about 700 million tonnes with uranium content ranging between 50 ppm and 200 ppm (as reported in the 2009 Red Book). No reliable estimate of the uranium resources in Egyptian phosphate ores has been made since 2008, when it was reported in the 2009 Red Book that it is possible the deposits contain up to 42 000 tU.

Black sands, a potential source of unconventional uranium resources, are considered the second most important unconventional source of uranium in Egypt. Monazite, one of the black sand ore minerals, is estimated to contain about 6 million tonnes of radiogenic and rare earth elements with potential economic and industrial returns. At some locations, such as in the El Borols area, the monazite contains up to 0.5% U and 6% Th, as well as 60% rare earth elements.

Uranium production

Historical review

Between 2007 and 2011, the NMA worked on the development of the small semi-pilot plant for the extraction of uranium from different rock types, and the evaluation of leaching and extraction efficiencies. Tests were carried out on uranium mineralisation from the Gattar (Eastern Desert) and Abu Zenima (South Sinai) projects to study the most suitable methods of dissolving uranium from granitic rocks (Gattar), and sedimentary rocks (Sinai), as well as the ideal factors for using the vat leaching system and extraction using the ion-exchange technique.

After completing the laboratory experiments, a flowsheet for the extraction of uranium from ores in the Gattar granite was developed. This was followed by the construction of the Gattar experimental yellowcake production unit with a capacity of 1 000 tonnes of ore materials at an average concentration of 200 ppm U (0.02% U), and a production rate of 300 kg of yellowcake annually. At the Abu Zenima project, a small heap leach pad was constructed in 2018 next to the experimental vat with a capacity of about 1 000 tonnes of uranium-bearing rock ore per batch, at an average concentration of 250 ppm U, and it is now in operation.

From 1999 to 2003, the NMA worked on the development of a semi-pilot plant for the extraction of uranium from phosphoric acid (purification of phosphoric acid through the extraction of uranium). The design capacity of this plant is 15 m^3/d of acid production, but unexpected technical problems caused a delay in production of yellowcake. The project was suspended due to difficulties relating to the low uranium content of phosphoric acid and difficulties in the extraction cycle. The semi-pilot plant for purification of phosphoric acid has since been converted to produce phosphoric acid for agricultural, food and other domestic purposes.

Status of production facilities, production capability, recent and ongoing activities, and other issues

In November 2017, the NMA began establishing the first production unit to leach uranium, in South Sinai, with a capacity of 4 000 tonnes of uranium-bearing ore per batch, using a heap leach and limited vat basin leaching process. At the Gattar project, the uranium is leached by placing the ores in vats or on a heap leach pad. In December 2019, the trial operation began extracting yellowcake by an ion-exchange process as an experimental production stage at the Abu Zenima project.

Future production centres

Egypt developed mine and processing pilot projects at Gattar and Abbu Zenima in 2001 and is planning to do the same at Abu Rusheid and El Sella in 2025. Depending on the results of these pilot projects, production centres could be constructed in the future.

Gattar project

The existing pilot production centre includes vat leaching (1 000 tonnes of uraniferous granitic ore capacity) and small-scale heap leaching (2 500 tonnes ore). The committed production centre will include the construction of a heap leaching pad, with a capacity of 10 000 tonnes ore.

Abu Zenima project

The existing pilot production centre includes vat leaching (capacity 4 000 tonnes of ore) and a heap leaching pad (1 000 tonnes of uraniferous ore).

Abu Rusheid project

The planned pilot production centre will include vat leaching (with a suitable tonnage of basement uraniferous rocks) and an ion-exchange unit for uranium extraction.

El Sella project

The planned pilot production centre will include a heap leaching pad and an ion-exchange unit for uranium extraction.

Ownership structure of the uranium industry

The uranium industry in Egypt is expressed as a system of small experimental units that do not contribute to global production and are owned by the government.

Employment in the uranium industry

The uranium industry supporting Egypt's experimental units has depended on specialised workers in this field since 1999, in addition to new technical staff and workers gaining work experience.

Production and/or use of mixed oxide fuels

Egypt does not produce or use mixed oxide fuels.

Environmental activities

All trial mining, trenching and drilling operations, as well as laboratories, are subject to environmental control and radiation safety regulations following guidelines of the International Atomic Energy Agency, and to the supervision, follow-up, and control of the Egyptian Nuclear and Radiological Regulatory Authority.

Uranium exploration and development expenditures and drilling effort – domestic

(Egyptian pounds – EGP)

	2018	2019	2020	2021 (expected)
Industry exploration expenditures	0	0	0	0
Government exploration expenditures	1 000 000	1 000 000	2 000 000	3 000 000
Industry development expenditures	0	0	0	0
Government development expenditures	500 000	500 000	1 000 000	1 000 000
Total expenditures	1 500 000	1 500 000	3 000 000	4 000 000
Industry exploration drilling (metres)	0	0	0	0
Industry exploration holes drilled	0	0	0	0
Industry exploration trenches (metres)	0	0	0	0
Industry trenches (number)	0	0	0	0
Government exploration drilling (metres)	1 500	2 000	1 550	3 100
Government exploration holes drilled	70	90	72	100
Government exploration trenches (metres)	360	480	330	500
Government trenches (number)	9	12	14	20
Industry development drilling (metres)	0	0	0	0
Industry* development holes drilled	0	0	0	0
Government development drilling (metres)	250	500	200	350
Government development holes drilled	12	22	8	20
Subtotal exploration drilling (metres)	0	0	0	0
Subtotal exploration holes drilled	0	0	0	0
Subtotal development drilling (metres)	0	0	0	0
Subtotal development holes drilled	0	0	0	0
Total drilling (metres)	1 750	2 500	1 750	3 450
Total number of holes drilled	82	112	80	120

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	0	2 000	
Open-pit mining (OP)	0	0	515	515	
Total	0	0	515	2 515	

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	515	515
Granite-related	0	0	0	2 000
Total	0	0	515	2 515

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	13 600	13 600

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	NA

Finland

Uranium exploration

Historical review

Uranium exploration in Finland was first carried out between 1955 and 1988, initially by the companies Atomienergia Oy, Imatran Voima Oy and Outokumpu Oy, and from 1973 by the Geological Survey of Finland (GTK). In the late 1980s, exploration activities were stopped. Exploration began again in the 2000s by Areva (now Orano) and some junior companies. In 2010, Areva closed down its Finnish subsidiary, and its exploration assets in Finland were purchased by Mawson Resources Ltd (now Mawson Gold Ltd). Uranium exploration in Finland has slowed since 2011, as Mawson's focus of exploration has shifted increasingly to gold.

Recent and ongoing uranium exploration

There is currently no uranium exploration in Finland.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Finland reports a total of 1 500 tU of in situ reasonably assured conventional resources, recoverable at costs of USD 80-130/kgU in the Palmottu and Pahtavuoma uranium deposits. No inferred conventional resources are reported.

Undiscovered conventional resources (prognosticated and speculative resources)

None reported.

Unconventional resources and other materials

Unconventional resources of uranium in the Talvivaara black schist-hosted Ni-Zn-Cu-Co deposit are approximately 19 400 tU at an average grade of 0.0017% U in the measured and indicated resources of 1 142 Mt, and about 25 500 tU at an average grade of 0.0017% U in the total mineral resources (measured, indicated and inferred) of 1 500 Mt, calculated from the 2020 resource update by Terrafame Oy.

Uranium production

Historical review

Uranium production in Finland has been confined to the now remediated Paukkajanvaara mine that operated as a pilot-scale mine between 1958 and 1961. In all, 40 000 tonnes of ore were excavated and the concentrates produced amounted to about 30 tU. As reported in the NEA 2006 Red Book Retrospective, the total historical production calculated from the mining register statistics is no more than 41 tU from 1958 to 1961.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1
Name of production centre	Terrafame mine in Sotkamo
Production centre classification	Committed
Date of first production	2024
Source of ore:	
Deposit name(s)	Talvivaara (Kuusilampi and Kolmisoppi)
Deposit type(s)	Black schist (metamorphosed black shale)
Recoverable resources (tU)*	8 700*
Grade (% U)	0.0017
Mining operation:	
Type (OP/UG/ISL)	OP
Size (tonnes ore/day)	41 000
Average mining recovery (%)	50
Processing plant:	
Acid/alkaline	Acid (heap leaching)
Type (IX/SX)	SX
Size (tonnes ore/day)	NA
Average process recovery (%)	90
Nominal production capacity (tU/year)	250
Plans for expansion	NA
Other remarks	Heap leaching by-product

* Overall recovery factor of 45% used in the estimate.

Future production centres

There is currently no uranium production in Finland. Between 2010 and 2015, Talvivaara Sotkamo Oy prepared for uranium recovery as a by-product from the Talvivaara deposit in Sotkamo, eastern Finland. The Talvivaara Ni-Zn-Cu-Co deposit is hosted by metamorphosed black shales in the Kainuu Schist Belt. It is a low-grade, large-tonnage deposit averaging 0.26 wt% Ni, 0.53 wt% Zn, 0.14 wt% Cu, 0.02 wt% Co, and 0.0017 wt% U.

Production of nickel, cobalt and zinc from the Talvivaara ore deposit commenced in 2008. The production process includes open-pit mining, crushing, heap leaching and metals recovery. The leach solution percolates to the bottom of the leach pads and is either recirculated through the heap or fed to metals recovery. During metals recovery, nickel, zinc, cobalt and copper are precipitated from the pregnant leach solution (PLS) and filtered to produce saleable metal products. After the target metals have been recovered, the solution is further purified to remove unwanted metals, which are directed to process waste gypsum ponds.

In 2010, Talvivaara Sotkamo Oy announced plans to recover uranium as a by-product using solvent extraction, resulting from the fact that a large part of uranium dissolves in the PLS during heap leaching. Dissolved uranium has largely ended up in the process wastes and partly in the Ni-Co sulphide concentrate product. Uranium has been present as an impurity in the Ni-Co sulphide consigned to the Norilsk Nickel refinery at Harjavalta, western Finland. Uranium residuals have been extracted from the nickel products at the Harjavalta Nickel Refinery, and reported to the Radiation and Nuclear Safety Authority (STUK). The Norilsk Nickel Harjavalta refinery has been licensed by the STUK to extract uranium at less than 10 tU/year. As of 31 December 2020, the total amount of natural uranium stored at Norilsk Nickel Harjavalta was about 3.6 tU.

During 2011-2013, the uranium solvent extraction plant was built as a new unit in the metals recovery complex of Talvivaara. In 2012, the Finnish government granted a uranium extraction licence to Talvivaara Sotkamo Oy in accordance with the nuclear energy legislation. In 2013, however, the Supreme Administrative Court returned the licence to the Finnish government for reassessment due to several changes in the operations of Talvivaara Sotkamo Oy after the licence decision, including the corporate reorganisation. Eventually, Talvivaara Sotkamo Oy filed for bankruptcy due to its financial problems in 2014. State-owned company Terrafame Oy acquired the operations and assets of Talvivaara Sotkamo Oy from its bankruptcy estate in 2015, and as of 1 January 2021, was carrying on the mining operations in Sotkamo.

In 2017, Terrafame Oy applied to the Finnish government for a licence to recover uranium as a by-product at Terrafame's mine in Sotkamo, in accordance with the nuclear energy legislation. In February 2020, the Finnish government granted a uranium extraction licence to Terrafame. However, the licence was appealed to the Supreme Administrative Court. In June 2021, the Supreme Administrative Court confirmed the uranium extraction licence that had been previously granted by the government. The mine site in Sotkamo currently includes an almost fully completed uranium solvent extraction plant from the time of Terrafame's predecessor, Talvivaara Sotkamo Oy. Terrafame expects to start uranium production in Sotkamo in 2024, after the establishment of the economic feasibility of uranium recovery and completion of an investment decision, final plant design, project implementation, deployment, and start-up of the uranium solvent extraction plant.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

Finland does not produce or use mixed oxide fuels.

Production and/or use of re-enriched tails

Re-enriched tails have not been used in 2019 and 2020.

Regulatory regime

The Mining Act regulates exploration and mining activities in Finland. All licences under the Mining Act are decided by the mining authority Tukes. An environmental permit according to the Environmental Protection Act is required for mining. The mine closure process is regulated by mining and environmental legislation, as well as a number of EU and other specifications.

The Radiation and Nuclear Safety Authority (STUK) is the regulatory body for uranium production, as specified in the Nuclear Energy Act and the Radiation Act. Production of uranium or thorium needs a licence from the Finnish government according to the Nuclear Energy Act. A licence application must be submitted to the government. Statements from different authorities (including STUK) are required for the decision on the licence, which is prepared by the Ministry of Economic Affairs and Employment and decided by the government.

According to the Mining Act of 2011, an exploration licence is required for uranium exploration (e.g. for drilling and trenching). Permit applications concerning a uranium mine under the Mining Act and the Nuclear Energy Act are handled jointly and decided on in a single decision by the government. A permit for a uranium mine requires that the mining activities be in line with the overall good of society, the municipality in question has given its consent and safety requirements are fulfilled.

STUK's regulatory control covers the radiation exposure of workers and the public, environmental monitoring, waste management, emergency preparedness, nuclear material accountancy and physical protection of nuclear materials. STUK verifies that safety and security requirements are fulfilled. Radioactive tailings are regarded as nuclear waste and are subject to funding for the future costs of waste management. Uranium concentrate export, controlled by the Ministry for Foreign Affairs, is also subject to national and international safeguards control.

The environmental impact assessment procedure is applied to all uranium mining projects, without any limitations on the annual amount of the extracted resources. In addition, other legislation to be applied for mining activities includes the Water Act, the Nature Conservation Act, the Wilderness Act, the Chemicals Act, the Land Use and Building Act, the Occupational Safety and Health Act, the Waste Act and various government decrees and decisions.

Uranium requirements

Four nuclear power plant units (two each at the Olkiluoto and Loviisa Nuclear Power Plants) with a total generating capacity of 2.8 GWe (net) are in operation, providing about 34% of domestic electricity generation. These four reactors require about 430 tU annually. Olkiluoto units are owned and operated by Teollisuuden Voima Oyj (TVO), and Loviisa units by Fortum Power and Heat Oy.

Construction of Finland's fifth nuclear power plant unit, TVO's Olkiluoto 3 (EPR; 1.6 GWe net), was completed in December 2021, and the unit will be connected to the national grid in early 2022. TVO selected European pressurised reactor (EPR) technology for the Olkiluoto 3 unit in 2003, and the Areva-Siemens Consortium started construction in 2005. It is expected that regular electricity production at the Olkiluoto 3 unit will begin in June 2022, 13 years later than originally planned.

In 2010, the Finnish Parliament ratified the decisions in principle (DIP) for the construction of two new reactors, one at the existing Olkiluoto site (OL4) by TVO and a single reactor at the greenfield Pyhäjoki site by Fennovoima. According to the DIP, the deadline for submitting the applications for the construction licences of these units was the end of June 2015.

In June 2015, TVO decided not to apply for a construction licence for OL4 during the validity of the DIP made in 2010. The reason was the delay of the start-up of the Olkiluoto 3 power plant unit. Consequently, the DIP made by the Finnish government and approved by parliament expired at the end of June 2015. TVO will remain prepared to apply for a new decision in principle for OL4. The application is subject to a separate decision.

Fennovoima is a new nuclear power company, established by a group of Finnish companies in 2007. It will build a nuclear power plant unit (Hanhikivi 1) in Pyhäjoki, northern Finland. Fennovoima has two main owners: Voimaosakeyhtiö SF Oy (with a 66% stake) and Rosatom's subsidiary RAOS Voima Oy (with 34%). Voimaosakeyhtiö SF is owned by Finnish energy and industrial companies.

A construction licence application for Fennovoima's Hanhikivi 1 unit was submitted to the Finnish government in 2015. Fennovoima expects that the construction licence for the Hanhikivi 1 unit will be granted by the government in 2022, and that the unit's construction will begin in 2023 with a view to start commercial operation around 2029. The nuclear power plant unit of Fennovoima (AES-2006; 1.2 GWe net) will be supplied by RAOS Project Oy, which is a part of Rosatom.

Supply and procurement strategy

TVO procures its nuclear fuel for the Olkiluoto nuclear power plant through a decentralised supply chain, entering into negotiations and making procurement contracts with each separate supplier at the various stages of the fuel production chain. There are several suppliers for each stage of the chain. Procurement operations are based on long-term contracts with suppliers. These companies have mining operations in many countries. Most of the uranium procured by TVO comes from Kazakhstan, Canada, and Australia, and the nuclear fuel assemblies ordered by the company are fabricated in Germany, Spain or Sweden.

The fuel assemblies used at Fortum's Loviisa nuclear power plant are completely of Russian origin. Nuclear fuel is acquired from the Russian company TVEL as a turnkey delivery, from the acquisition of the uranium to the fabrication of the fuel assemblies. Conversion, enrichment and fuel fabrication are carried out by TVEL, which acquires the uranium used in the fuel assemblies from ARMZ Uranium Holding Co. In 2020, the uranium used in the Fortum's fuel assemblies originated from the Krasnokamensk, Khiagda and Dalur mines.

Fennovoima will acquire the nuclear fuel as an integrated fuel supply from TVEL. The integrated delivery will cover the procurement of the uranium and the manufacturing of the fuel for the first ten years of operation of Hanhikivi 1. The fuel supply agreement between Fennovoima and TVEL was approved by the Euratom Supply Agency in 2014.

Uranium policies, uranium stocks and uranium prices

Nuclear energy legislation

The legal basis of the use of nuclear energy in Finland consists of the Nuclear Energy Act and the Nuclear Energy Decree. The purpose of nuclear energy legislation is to ensure that the use of nuclear energy is in line with the overall good of society, safe for people and the environment, and that its use does not enable the proliferation of nuclear weapons. The use of nuclear energy creates several obligations for the licensee: the licensee must, among other things, ensure the safety of operations, manage the nuclear waste created through the operations, and assume responsibility for all nuclear waste management costs. Nuclear waste management costs are prepared for by collecting funds in advance in the price of electricity and depositing them in the National Nuclear Waste Management Fund.

The Nuclear Energy Decree and government decisions have been issued based on the Nuclear Energy Act. The government decisions concern nuclear plant safety, safety arrangements, preparedness arrangements, and the final disposal of operating waste and spent nuclear fuel. Based on the authorisation by the nuclear energy legislation, the STUK publishes detailed safety requirements for the use of nuclear energy. Radiation safety is regulated by the Radiation Act and the Radiation Decree. The Nuclear Liability Act stipulates that the licensee must have nuclear liability insurance that will compensate for injuries caused to outsiders by a possible nuclear accident, to the extent decreed by law.

Nuclear waste management

Spent nuclear fuel from the Olkiluoto and Loviisa Nuclear Power Plants is stored in the water pools of the fuel storage facilities at Olkiluoto and Loviisa until finally disposed of in the Olkiluoto bedrock in the municipality of Eurajoki. Posiva Oy, a company owned by TVO and Fortum, is responsible for the final disposal of the spent nuclear fuel of the owners. Spent nuclear fuel from the nuclear power plants of TVO and Fortum will be packed in copper canisters and embedded in Olkiluoto bedrock at a depth of 400-450 m. The final disposal of spent nuclear fuel is based on the use of multiple release barriers to ensure that the nuclear waste cannot be released into organic nature or become accessible to humans. The release barriers include the ceramic, solid state of the fuel, the disposal canister, the bentonite buffer, the backfilling of the tunnels and the surrounding rock.

Posiva is currently constructing the final disposal facility in Olkiluoto. In 2015, Posiva received a construction licence from the Finnish government for its final disposal system, consisting of a nuclear fuel encapsulation plant and final disposal facility. The excavation of the final disposal facility began in 2016, and the construction of the encapsulation plant started in 2019. The current plan is to start final disposal in the mid-2020s.

With respect to the Hanhikivi 1 project, Fennovoima has two alternative final disposal locations in its environmental impact assessment (EIA) programme: Pyhäjoki or Eurajoki. Fennovoima aims to engage in long-term final disposal co-operation with Posiva and its owners (TVO and Fortum).

Uranium stocks

The nuclear power utilities maintain reserves of fuel assemblies from seven months to one year's use, although the legislation demands only five months' use.

Uranium prices

Due to commercial confidentiality, price data are not available.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	0	0	500	500
Open-pit mining (OP)	0	0	1 000	1 000
Total	0	0	1 500	1 500

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	0	0	500	500
Conventional from OP	0	0	1 000	1 000
Total	0	0	1 500	1 500

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Metamorphite	0	0	500	500
Intrusive	0	0	1 000	1 000
Total	0	0	1 500	1 500

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining	15	0	0	15	0
Underground mining	15	0	0	15	0
Total	30	0	0	30	0

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	30	0	0	30	0
Total	30	0	0	30	0

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	30	0	0	30	0
Total	30	0	0	30	0

Mid-term production projection (tonnes U/year)

2021	2022*	2025*	2030*	2035*	2040*
0	0	N/A	N/A	N/A	N/A

* By-product of nickel production from the Talvivaara black schist-hosted Ni-Zn-Cu-Co deposit (unconventional resources).

Re-enriched tails production and use

(tonnes natural U-equivalent)

Re-enriched tails	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Production	0	0	0	0	0
Use	843	0	0	843	0

Net nuclear electricity generation

	2019	2020
Nuclear electricity generated (TWh net)	22.9	22.4

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
2 780	2 780	4 410	4 410	5 110	5 110	4 610	4 610	2 830	4 610

Annual reactor-related uranium requirements* to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
426	720	690	750	700	750	700	770	450	770

* Refers to natural uranium acquisitions, not necessarily consumption during the calendar year.

France

Uranium exploration and mine development

Historical review

Uranium exploration began in 1946, focusing on previously discovered deposits and a few occurrences discovered during radium exploration. In 1948, exploration led to the discovery of the La Crouzille deposit, which at one time was of major importance. By 1955, additional deposits had been identified in the granite areas of Limousin, Forez, Vendée and Morvan. Prospecting activities were subsequently extended to sedimentary formations in small intra-granitic basins and terrigeneous formations derived from eroded granite mountains, mainly located north and south of the Massif Central.

Recent and ongoing uranium exploration and mine development activities

No domestic activities have been carried out in France since 1999.

As of 2020, Orano S.A. (formerly Areva S.A.) has been working outside France focusing on the discovery of exploitable resources in Canada, Gabon, Kazakhstan, Mongolia, Namibia and Niger. In Canada, Kazakhstan and Niger, Orano is also involved in uranium mining operations. In addition, as a non-operator, it holds shares in several mining operations and research projects in different countries. In 2020, Orano started exploration in Uzbekistan.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Orano no longer reports resources or reserves in France since the historic data on which these estimates are based do not conform to modern international standards.

Undiscovered conventional resources (prognosticated and speculative resources)

No systematic appraisal has been made of undiscovered resources.

Uranium production

Status of production facilities, production capability, recent and ongoing activities and other issues

Following the closure of all uranium mines in 2001, all ore processing plants were shut down, dismantled and the sites reclaimed.

In France, a total of 244 sites, ranging from exploration sites to mines of various sizes, 8 mills and 17 tailing deposits (containing a total of 52 Mt of tailings) are the result of the production of about 80 000 tU. All of these sites have been remediated. Monitoring continues at only the most important sites, and 17 water treatment plants were installed to clean drainage from the sites. Orano is responsible for the management of 234 of these sites.

The purpose of remediation is to:

- ensure public health and safety;
- limit the residual impact of previous activities, to as low as reasonably achievable (ALARA);
- integrate the industrial sites into landscape;
- maintain a dialogue and consultation with local populations;
- allow the reconversion of the former sites to new activities, such as tourism, industry, agriculture and energy (solar panels).

Future production centres

There are no plans to develop new production centres in France in the near future.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

The annual licensed capacity of MOX fuel production in France is about 195 tHM, roughly corresponding to 1 560 tU equivalent (tNatU) using the recommended Red Book conversion factor. Actual yearly production of MOX in France varies below this licensed capacity in accordance to contracted quantities. Most of the French MOX production is used to fuel French nuclear power plants (a total of about 125 t/yr, or 1 000 tNatU) and the remainder is delivered abroad under long-term contract arrangements.

Production and/or use of reprocessed uranium

In France, reprocessed uranium is produced at the la Hague reprocessing plant. Électricité de France (EDF) produces around 1 000 tU of spent fuel annually. Reprocessed uranium was recycled at the EDF nuclear power plant of Cruas. The last fuel assemblies containing reprocessed uranium were loaded in 2013. EDF signed in 2018 contracts for the recycling, starting in 2023, of reprocessed uranium (RepU) for use in PWRs. This solution enables EDF to diversify its uranium supply sources, allowing for savings of around 10-15% of its natural uranium requirements. It also ensures completeness of the French nuclear cycle, by reusing 96% of the nuclear material contained in spent fuel.

Regulatory regime

In France, mines are nationally regulated according to the mining code and processing plants according to regulations specified in the legislation governing the operation of installations that present environmental risks (ICPE – *installation classée pour la protection de l'environnement*). These regulations are applied by regional environmental authorities (DREAL – Directions régionales de l'Environnement, de l'Aménagement et du Logement) on behalf of the prefect (the state representative in a particular department or region).

In order to open a mine, the mining company must present a report to the regional authorities that will allow them to confirm that the project will be operated in accordance with all regulations. Once this is confirmed, a public enquiry must be held. If these processes are successfully completed, the mining company will be allowed to open the mine according to requirements laid out in an *Ordre du Préfet*. When mining is completed, the mining company must prepare a report for local authorities who can then give authorisation for decommissioning through an *Ordre du Préfet*.

In theory, according to the mining code, after remediation and a period of monitoring to verify that there is no environmental impact, the mining company can transfer the responsibility of the site to the state. However, if there is a problem, the state asks the mining company to remediate it.

After decommissioning, the mining company retains responsibility for the site, including monitoring and maintenance. There has not been a transfer of responsibility for a uranium mine from the mining company to the state because Orano is always present. However, Orano is in discussions with the authorities regarding the transfer of responsibility.

The cost of mine remediation is the responsibility of the mining company. In the case of processing plants (mills), local authorities request financial guarantees for the costs of all remediation works and monitoring. A draft revision of the mining code is currently under development.

Uranium requirements

France has 56 nuclear power reactors in operation (supplying 61 370 MWe) and 1 EPR reactor under construction at the Flamanville site. The development strategy for nuclear power is related to the goals set forth by the Energy Transition for Green Growth Act and the Multiyear Energy Plan (MEP), published in April 2020. Nuclear power development will depend, in particular, on developments in renewable energy and decisions of the Nuclear Safety Authority regarding the potential lifetime extension of the existing power plants.

In the MEP, a total of 14 power reactors are planned to be shut down in order to reduce the share of nuclear in France's electricity generation mix from the current 75% to 50% by 2035.

In 2006, Areva began work at the Tricastin site on construction of the Georges Besse II uranium centrifuge enrichment plant to replace the Eurodif gaseous diffusion plant that had been in service since 1978. In 2012, production at the Eurodif plant was stopped and the facility will be dismantled in the coming years. The Georges Besse II facility successfully reached its full production capacity of 7.5 million SWUs in 2016, on schedule as planned. The most recent qualification tests carried out have confirmed the performance capabilities of the plant's equipment with its industrial facilities showing rates of efficiency in excess of 99%.

Supply and procurement strategy

Since France is a net importer of uranium, its policy towards procurement is one of supply diversification. French entities participate in uranium exploration and production outside France within the regulatory framework of the host countries. Uranium is also purchased under short- or long-term contracts, either from mines in which French entities have shareholdings or from mines operated by third parties.

Uranium policies, uranium stocks and uranium prices

Uranium stocks

EDF possesses strategic uranium inventories, the minimum level of which has been fixed at the equivalent of a few years' forward consumption to offset possible supply interruptions.

Uranium prices

Information on uranium prices is not available.

Uranium exploration and development expenditures – non-domestic

(In EUR millions)

	2018	2019	2020	2021 (expected)
Industry exploration expenditures	0	0	0	0
Government* exploration expenditures	35	30	28	27
Industry development expenditures	0	0	0	0
Government* development expenditures	NA	NA	NA	NA
Total expenditures	35	30	28	27

* Orano S.A., a state majority-owned company. In previous reports, these expenditures were attributed to industry. Government expenditures refer to those corresponding to majority government funding.

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining[1]	5 427	0	0	5 427	0
Underground mining[1]	1 511	0	0	1 511	0
Open-pit and underground[2]	73 925	0	0	73 925	0
Co-product/by-product	115	0	0	115	0
Total	80 978	0	0	80 978	0

1. Pre-2018 totals may include uranium recovered by heap and in-place leaching.

2. Not possible to separate in historic records.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	80 863	0	0	80 863	0
Other or unspecified methods*	115	0	0	115	0
Total	80 978	0	0	80 978	0

* Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	16 781	0	0	16 781	0
Granite-related	63 683	0	0	63 683	0
Metamorphite	395	0	0	395	0
Volcanic-related	1	0	0	1	0
Black shale	3	0	0	3	0
Other or unspecified	115	0	0	115	0
Total	80 978	0	0	80 978	0

Mixed oxide fuel production and use
(tonnes natural U-equivalent)

Mixed oxide (MOX) fuel	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Production	24 397	870	635	25 902	NA
Use	NA	NA	NA	NA	NA
Number of commercial reactors using MOX	22	22	23	23	23

Reprocessed uranium use
(tonnes natural U-equivalent)

Reprocessed uranium	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Production	28 982	1 026	980	30 988	NA
Use	5 300	NA	0	5 300	0

Net nuclear electricity generation (TWh net)

	2019	2020
Nuclear electricity generated (TWh net)	379.5	335.4

Installed nuclear generating capacity to 2040
(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
63 000	61 000	61 000	63 000	NA	NA	NA	NA	NA	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)
(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
5 039	6 034	7 000	7 300	5 700	NA	4 500	NA	NA	NA

Germany

Uranium exploration and mine development

Historical review

After World War II, and until reunification in 1990, exploration for uranium occurred in two separate countries in what is today Germany:

Federal Republic of Germany (FRG) before 1990

Starting in 1956, exploration was carried out in several areas of geological interest: the Hercynian Massifs of the Black Forest, Odenwald, Frankenwald, Fichtelgebirge, Oberpfalz, Bayerischer Wald, Harz, the Paleozoic sediments of the Rheinisches Schiefergebirge, the Permian volcanics and continental sediments of the Saar-Nahe region and other areas with favourable sedimentary formations. The initial phase included hydrogeochemical surveys, car-borne surveys, field surveys and, to a lesser extent, airborne prospecting. Follow-up geochemical stream sediment surveys, radon surveys and detailed radiometric work, followed by drilling and trenching, were carried out in promising areas. During the reconnaissance and detailed exploration phases, both the federal and state geological surveys were involved, whereas the actual work was carried out mainly by industrial companies.

Three deposits of economic interest were found: (1) the partly high-grade hydrothermal deposit near Menzenschwand in the southern Black Forest, (2) the sedimentary Müllenbach deposit in the northern Black Forest, and (3) the Grossschloppen deposit in north-eastern Bavaria. Uranium exploration ceased in Western Germany in 1988 but by then about 24 800 holes had been drilled, totalling about 354 500 m. Total expenditures were on the order of USD 111 million.

Former German Democratic Republic (GDR) before 1990

Uranium exploration and mining were undertaken from 1946 to 1953 by the Soviet stock company, SAG Wismut. These activities were centred around old mining locations of silver, cobalt, nickel, and other metals in the Erzgebirge (Ore Mountains) and in Vogtland, Saxony, where uranium had first been discovered in 1789.

Uranium exploration had started in 1950 in the vicinity of the radium spa at Ronneburg. Using a variety of ground-based and aerial techniques, the activities covered an extensive area of about 55 000 km^2 in the southern part of the GDR. About 36 000 holes in total were drilled in an area covering approximately 26 000 km^2. Total expenditures for uranium exploration over the life of the GDR programme were on the order of 5.6 billion GDR marks.

Uranium mining first began shortly after World War II in cobalt and bismuth mines near Schneeberg and Oberschlema (a former famous radium spa). During this early period more than 100 000 people were engaged in exploration and mining activities. The rich uraninite and pitchblende ore from the vein deposits was hand-picked and shipped to the USSR for further processing. Lower-grade ore was treated locally in small processing plants. In 1950, the central mill at Crossen near Zwickau, Saxony, was brought into operation.

In 1954, a new joint Soviet-German stock company was created, Sowjetisch-Deutsche Aktiengesellschaft Wismut (SDAG Wismut). The joint company was held equally by both governments. All production was shipped to the USSR for further treatment. The price for the final product was simply agreed upon by the two partners. Profits were used for further exploration.

At the end of the 1950s, uranium mining was concentrated in the region of eastern Thuringia. From the beginning of the 1970s, the mines in eastern Thuringia provided about two-thirds of SDAG Wismut's annual production.

Between the mid-1960s and the mid-1980s, about 45 000 people were employed by SDAG Wismut. In the mid-1980s, Wismut's employment decreased to about 30 000. In 1990, only 18 000 people worked in uranium mining and milling, and the number of employees has declined since as remediation activities are completed.

Recent and ongoing uranium exploration and mine development activities

There have been no exploration activities in reunified Germany since the end of 1990. Several German mining companies, however, did perform exploration abroad (mainly in Canada) through 1997.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Identified conventional resources were last assessed in 1993. These identified conventional resources occur mainly in the closed mines that are in the process of being decommissioned. Their future availability remains uncertain.

Undiscovered conventional resources (prognosticated and speculative resources)

All undiscovered conventional resources are reported as speculative resources in the cost category <USD 260/kgU.

Unconventional resources and other materials

None reported.

Uranium production

Historical review

Federal Republic of Germany (FRG) before 1990

In the FRG, a small (125 tonnes per year) uranium processing centre in Ellweiler, Baden-Württemberg, began operating in 1960 as a test mill. It was closed on 31 May 1989 after producing a total of about 700 tU.

Former German Democratic Republic (GDR) before 1990

Two processing plants were operated by SDAG Wismut in the territories of the former GDR. A plant at Crossen, near Zwickau in Saxony, started processing ore in 1950. The ore was transported by road and rail from numerous mines in the Erzgebirge. The composition of the ore from the hydrothermal deposits required carbonate pressure leaching. The plant had a maximum capacity of 2.5 million tonnes of ore per year. Crossen was permanently closed on 31 December 1989.

The second plant at Seelingstadt, near Gera, Thuringia, started ore processing operations in 1960 using the nearby black shale deposits. The maximum capacity of this plant was 4.6 million tonnes of ore per year. Silicate ore was treated by acid leaching until the end of 1989. Carbonate-rich ores were treated using the carbonate pressure leaching technique. After 1989, Seelingstadt's operations were limited to the treatment of slurry produced at the Königstein mine using the carbonate method.

A total of over 200 000 tU was produced in the GDR between 1950 and 1989.

Status of production facilities, production capability, recent and ongoing activities and other issues

There is no commercial production of uranium in Germany today. Decommissioning of the historic German production facilities started in 1989 (former FRG) and 1990 (former GDR). Between 1991 and 2020, uranium recovery from mine water treatment and environmental restoration amounted to a total of 2 631 tU. Since 1992, all uranium production in Germany has been derived from the clean-up operations at the Königstein mine. In 2020, conversion work of the water treatment facility at the Königstein mine finally ended uranium production in Germany. The existing system was adapted to future requirements, whereby the technological process phase of selective uranium separation was omitted owing to the decreasing content of uranium and heavy metals in the flood water in recent years. Future water treatment at the Königstein mine site will still be required but without any special separation of uranium. This brings an end to uranium mining in Germany after almost 75 years.

Ownership structure of the uranium industry

The production facilities in the former GDR were owned by the Soviet-German company Wismut (SDAG Wismut). After reunification, the German Ministry of Economy inherited the ownership from SDAG Wismut. The German federal government through Wismut GmbH took responsibility for the decommissioning and remediation of all production facilities. The government retains ownership of all uranium recovered in clean-up operations.

In August 1998, Cameco completed its acquisition of Uranerz Exploration and Mining Ltd (UEM), Canada, and Uranerz USA Inc. (UUS), from their German parent company Uranerzbergbau GmbH (Preussag and Rheinbraun, 50% each). As a result, there remains no commercial uranium industry in Germany.

Employment in the uranium industry

All employment is engaged in decommissioning and rehabilitation of former production facilities. Employment decreased from 1 010 in 2018 to 911 in 2020.

Future production centres

None reported.

Uranium policies, uranium stocks and uranium prices

According to the energy concept 2010, the federal government decided to phase out use of nuclear power for commercial electricity generation on a staggered schedule. As of 2021, with the adoption of the Thirteenth Act amending the Atomic Energy Act (*Dreizehntes Gesetz zur Änderung des Atomgesetzes*), all reactors will be shut down by no later than the end of 2022. The German Bundestag (parliament) passed the amendment on 30 June 2011, and it came into force on 6 August 2011. For the first time in the modern history of Germany, a fixed deadline has been laid down in law for the end of the use of nuclear power in the country. The withdrawal is to be undertaken in stages with specific shutdown dates. On 11 November 2022, however, the Bundestag agreed to extend the duration of the operations of the three nuclear power plants operating in Germany at the time until 15 April 2023.

A total of 37 nuclear power plants have been built in Germany and put into commercial operation since 1962. In 2020, there were six nuclear power plants operating with installed generating capacity of approximately 8.1 GW. The final shutdown schedule for these six remaining nuclear power plants is as follows: in 2021, Grohnde, Gundremmingen C and Brokdorf; and in 2022, the three newest nuclear power plants, Isar 2, Emsland and Neckarwestheim 2.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	3 000	
Total	0	0	0	3 000	

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	3 000	
Total	0	0	0	3 000	

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	4 000	
Total	0	0	0	4 000	

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	4 000	
Total	0	0	0	4 000	

Historical uranium production by processing method

(recoverable tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Other methods*	2 600	24	7	2 631	0
Total	219 765	24	7	219 796	0

* Includes mine water treatment and environmental restoration.

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	74 000

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
7	100	0	0	0	0	0	0	7	100

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres	1 010	982	911	857
Employment directly related to uranium production	NA	NA	NA	NA

Mixed oxide fuel production and use

(tonnes natural U-equivalent)

Mixed oxide (MOX) fuel	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Production	0	NA	NA	NA	NA
Use	6 730	NA	NA	NA	NA
Number of commercial reactors using MOX		NA	NA		

* Reactors loading fresh MOX.

Re-enriched tails production and use

(tonnes natural U-equivalent)

Re-enriched tails	Total through end of 2017	2018	2019	2020	Total through end of 2020	2021 (expected)
Production	NA	NA	NA	NA	NA	NA
Use	NA	0	0	0	0	0

Reprocessed uranium use

(tonnes natural U-equivalent)

Reprocessed uranium	Total through end of 2017	2018	2019	2020	Total through end of 2020	2021 (expected)
Production	NA	0	0	0	0	0
Use	NA	NA	NA	NA	NA	NA

Net nuclear electricity generation

	2019	2020
Nuclear electricity generated (TWh net)	71	61

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
8 113	8 113	0	0	0	0	0	0	0	0

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
1 159	1 012	0	0	0	0	0	0	0	0

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	NA	NA	NA	NA	NA
Producer	NA	NA	NA	NA	NA
Utility	NA	NA	NA	NA	NA
Total	NA	NA	NA	NA	NA

Guyana

Uranium exploration and mine development

Historical review

The British Guiana Geological Survey, a former independent department in charge of natural resources in Guyana and supported by the United Kingdom, was originally responsible for mineral development. The Geological Survey Department worked intensively through the colonial development and welfare project No. D 2792 (Continuation & Expansion of Geological Survey) from 1956 to 1960. This project made provision for the expansion of the Geological Survey Department to carry out intensive mineral development. In June 1958, a geologist with specific experience in the geology of uranium arrived in Georgetown to organise exploratory operations for radioactive minerals and other key minerals such as beryllium. An occurrence of radioactive material discovered on the railway line under construction between Kaituma River and the property of the Northwest Guiana Mining Company, Ltd, was examined in some detail by ground and airborne surveys but proved to be euxenite – a refractory mineral. Nonetheless, investigations were extended to lithium minerals required in the nuclear power industry, as well as to radioactive minerals.

The Guyana Geology and Mines Commission (GGMC), established in 1979, is presently in charge of geological mapping throughout Guyana. The Geological Services Division (GSD) works to help the GGMC achieve its mission to "provide effective stewardship of our mineral and petroleum resources by ensuring increased opportunities for development (exploration, documentation and extraction), as well as to promote and support increased investment in the mining and related sectors". To examine and explore Guyana's uranium content, regional private programmes were launched.

The Moruwa Formation in Guyana was first investigated by Cominco Ltd during the period 1967-1975. Four holes were drilled, but the venture for them was not successful (Gibbs and Barron, 1993[*]) even though they found high uranium-bearing lateritic conglomerate boulders in the river. In the 1970s and 1980s, there were reports of possible unconformity-type uranium deposits (Workman and Breede, 2012[†]).

Between 1968 and 1970, Denison Mines Corp. investigated the potential for uranium in palaeo-placers in the conglomerate Roraima Formation. An airborne scintillometer survey was part of the project. Eleven anomalies were discovered (several of them minor), and four were chosen for additional investigation, including diamond drilling (vertical holes). Anomalies were attributed to the mass impacts of cliff exposures and thorium concentrations in sediments, but no significant results were found.

Compagnie Générale des Matières Nucléaires ("COGEMA") then carried out exploration in Guyana from 1979 to 1984 and discovered numerous uranium prospects and showings through simple ground and airborne scintillometer surveys along the periphery of the basin. COGEMA first chose Mahdia and Kurupung as the bases for their stream sediment collection workers since they had daily air service from Georgetown at that time. Portable boats and helicopters equipped with scintillometers were employed to conduct effective sampling of the interior of the area. They

* Gibbs, A.K. and C.N. Barron (1993), *The Geology of the Guiana Shield*, Oxford University Press, New York.

† Workman A. and K. Breede (2012), "Technical review and mineral resource estimates of the Aricheng C and Aricheng West structures, Kurupung Uranium Project. Mazaruni District, Guyana for U_3O_8 Corp.", Watts, Griffis and McOuat, Toronto.

moved unevenly and widely across the country to pick up any aberrant locations rather than identify and delineate anomalies on the ground like a grid survey would.

The survey crisscrossed the surrounding Anarabisi and Aricheng districts many times, so Kurupung was a fortunate choice. These resulted in 4 and 3.5 times the background radiation, respectively. COGEMA focused research on the area between Aricheng and Anarabisi. A number of sub-prospects were located within this district, and they were thoroughly studied utilising ground-based mapping, soil sampling, pitting, scintillometer surveys, and intensive drilling with diamond and percussion rigs. A number of possibilities were drilled in the Kurupung/Aricheng area. From stream sediments in Aricheng came the highest reading of 50 ppm uranium (0.005% U) in the country. Initially, 2 800 stream sediment samples were involved and 3 400 profile line kilometres were flown.

Merume, which is in the south, and Anarabisi, which is in the north, have uranium outcrops (uraninite and chalcocite) of 70 km spread out in eight locations (Workman and Breede, 2012). An assay sample from this vein contained 3 040 ppm U (0.304% U). A total of 253 diamond drill holes were drilled, with the deepest being ARNO 0001 at Aricheng North. Uranium mineralisation was identified in the Kurupung-Anarabisi granite batholith and in the Haimaraka basement shales.

COGEMA also investigated uranium in the Iwokrama Formation acid volcanics and differentiated granitoids between 1980 and 1984. In most accessible places north of the Takatu Graben, mainly in areas accessible by 4WD track or boat, extensive regional investigations were carried out. The completed tasks included granite sampling, alluvial mud sampling, ground and airborne scintillometer surveys, and later, systematic grid-based airborne radiometric surveys in a variety of regions, as well as extensive geological mapping and sampling. GGMC chemical data indicated that more U is found in stream sediments derived from granitic areas and Iwokrama Formation acid volcanics, and this was confirmed by COGEMA. In GGMC stream sediments, the maximum quantity of U and Th is 27 ppm, while the maximum amount of U and Th in rocks is 20.7 ppm (0.003% U) and 48.2 ppm, respectively. The maximum amount observed by COGEMA from the mud bank sample was 16 ppm U (0.0016% U). GGMC granite rock samples continued to show the highest uranium values; however, four laterite samples and two hornfelsed Roraima Formation mudstone samples also contained more than 10 ppm U (0.001% U).

Between 1980 and 1983, a United Nations team investigated a carbonatite complex for rare earth minerals at Muri Mountain, in southern Guyana on the border with Brazil. The work included an airborne radiometric survey, radioactive and magnetic ground surveys, stream sediment, soil and rock sampling, as well as diamond drilling. The GGMC reported assays in rock of up to 43 ppm U (0.0043% U).

Recent and ongoing uranium exploration and mine development activities

Over the last ten years, no noteworthy uranium exploration has taken place in Guyana. However, there were three uranium exploration ventures of note: Prometheus Resources (Guyana) Inc. of U_3O_8 Corp. (hereafter referred to as "U_3O_8 Corp"), a Canadian company; Pharsalus Gold Inc., a wholly owned subsidiary of Australia-based Azimuth Resources Ltd and Raven Minerals Corp. U_3O_8 Corp. provided the most significant results.

The initial public offering of shares by U_3O_8 Corp. was made in December 2006. The company was given large-scale reconnaissance permissions and prospecting licences for uranium in the Rupununi, Potaro, Mazaruni, Cuyuni and Barama River basins. Prospecting was also undertaken in Kato, Monkey Mountain and Paramakatoi (Colchester and La Rose, 2010[‡]). Prior to this, the company's exploration had consisted primarily of confirmatory work at some of the more advanced historical prospects. This included rock chip sampling, sampling of discarded drill core, thin section and polished section work, and electron microprobe examination of mineralised

‡ Colchester M. and J. La Rose, (2010), Our Land, Our Future: Promoting Indigenous Participation and Rights in Mining, Climate Change and other Natural Resource Decision-making in Guyana, Amerindian Peoples Association, Forest Peoples Programme and The North-South Institute, Georgetown, Guyana, www.forestpeoples.org/sites/fpp/files/publication/2010/08/guyanaourlandourfuturejun10eng.pdf (accessed 2 July, 2021).

samples. In 2007, exploration work included ground radiometric surveys designed to confirm airborne radiometric anomalies in the Kurupung batholith and to provide more detail on their form and location. The project covered the Kurupung batholith (granite and granodiorite) and surrounding country rocks (greenstone) next to areas of the Roraima Basin (epiclastic sedimentary strata). The initial diamond drilling was designed to twin and test mineralised intervals reported by COGEMA to the GGMC. After initial confirmation of the presence of mineralisation in the twin holes, drilling progressively stepped out to follow the mineralised structure along strike and down-dip. More than 7 305 metres of drilling was undertaken in 51 bore holes on the Aricheng North, Arichen South and Aricheng West structures. U_3O_8 Corp. resource drilling defined four uranium deposits in the Aricheng South, North, West and C zones of the Kurupung Project. These findings suggest that Kurupung could host a large uranium system comparable in size to other peer deposits such as Coles Hill in Virginia (United States), Michelin in Labrador (Canada) and Valhalla in Queensland (Australia). Currently, however, there are no active permits for any of the three companies.

Since U_3O_8 Corp. left Guyana in 2012, there has been no significant exploration, but the GGMC continues to conduct annual geochemical projects to map the country's mineral potential. In a bid to fulfil this mandate, the GSD continues to play its part in exploring geology and mineral resources around the country. In recent years, GGMC chemical data from the Permission for Geological and Geographical Survey (PGGS) areas for both light and heavy rare earth elements has shown that uranium levels are higher than other elements, ranging from more than 2.7 to 296 ppm (0.0003% U to 0.03% U). In 2020, however, no project work was done.

GGMC is slated to continue to carry out geochemical survey projects in Guyana's interior, beginning in September 2021. The majority of uranium discoveries thus far, including the Aricheng South, West, North and C resources, will be used to identify potential targets that are now being investigated in the field, in order to increase the inventory of mineralised structures for future resource extension. Development of resource estimates is possible, given the significant exploratory work already undertaken.

Uranium resources

In 2012, U_3O_8 Corp. estimated the uranium resources of the Aricheng structures (Kurupung area) in accordance with National Instrument 43-101.

Identified conventional in situ resources (reasonably assured and inferred resources)

Structure	Indicated			Inferred		
	Ore (t)	Grade (%U)	U (t)	Ore (Mt)	Grade (%U)	U (t)
Aricheng C	686 000	0.07	4 70	1 110 000	0.08	884
Aricheng West	749 000	0.07	5 30	2 518 000	0.06	1 549
Aricheng South	1 895 000	0.10	8 06	223 000	0.09	199
Aricheng North	782 000	0.08	1 430	422 000	0.08	315
Total Kurupung	4 112 000	0.08	3 236	4 273 000	0.07	2 947

Mineral Resources were estimated using an inverse distance squared (ID2) block model, constrained to a geological model with a minimum horizontal width of 2 m. A cut-off grade of 0.042% U was used for reporting of the resources. No deductions for mining recovery or otherwise were included in this estimate and mineral resources were estimated using an assumed price of USD 55/lb U_3O_8 (USD 143/kgU).

Undiscovered conventional resources (prognosticated and speculative resources)

Guyana does not report resources in any other category than reasonably assured resources.

Environmental activities and socio-cultural issues

Many exploration concessions have had an immediate impact on ancestral lands (titled and untitled). Toshaos and leaders from Region 8 complain, for example, that large-scale uranium and gold licences associated with U_3O_8 Corp. and Mahdia Gold Corp. had a direct impact on the Patamona people's traditional lands and territory. Furthermore, they argue that the affected Amerindian villages lack basic information on these mining interests, as well as the specific mining and exploration intentions in Region 8.

Moreover, social conditions in mining villages could have received more attention. The GGMC, in partnership with the Ministries of Health and Education, could have developed, monitored and enforced minimum acceptable standards. The GGMC could have also worked with the Ministry of Health and the Guyana Forestry Commission. To comply with the standards of the Guyanese Environmental Protection Agency ("EPA"), the existing regulations contain a provision for the filing of an Exploration Plan.

Regulatory regime

Mining operations and environmental monitoring in Guyana are governed by the GGMC. Support is also given by the Environmental Protection Agency (EPA) and Guyana Forestry Commission (GFC).

The regulatory regime for uranium mining in Guyana is the Guyana Geology and Mines Commission (CGMC), an independent body that regulates mining of minerals in Guyana.

All activities are covered by the following legislation:

- Order made under the Mining Act (No. 10 of 1989) Section 16 – This Order may be cited as the Guyana Geology and Mines Commission "Prospecting for Uranium, Radioactive Minerals and Rare Earth Elements" (Reservation Order 2006 that came into effect on the 23 October 2006).
- The Mining Act, No. 20 of 1989 (the "Mining Act") grants licences and authorisation for mineral prospecting, mining and development, as well as geological and geophysical investigations. The GGMC reviews and approves all investment projects involving the extraction of mineral resources in general. The government of Guyana passed the Environmental Protection Act in 1996 that requires an environmental permit from the Guyana Environmental Protection Agency before a mining property can be put into production.

The GGMC is tasked with promoting all development, mining and mineral exploration. It also provides technical assistance and advice in mining, mineral processing, mineral utilisation and marketing of mineral resources. In its current form, the commission has a remit for: promotion of mineral development; research in exploration, mining, and utilisation of minerals and mineral products; enforcement of the conditions of mining licences; collection of rentals, fees, charges, levies, etc. payable under the Mining Act. The government of Guyana (GGMC) has granted licences and permissions regarding mineral prospecting, mining and development as well as geological and geophysical surveys. All investment projects that involve the extraction of mineral resources are generally reviewed and approved by the GGMC.

National policies relating to uranium

With respect to energy in the mining industries, it is the government's policy to:

- increase end-use energy conservation and efficiency;
- achieve grid-tied cogeneration of electricity and industrial steam;
- reduce the local environmental impacts due to energy production;

- improve corporate management practices with respect to standards for energy management systems (EnMS);
- enhance the socio-economic development of the surrounding communities.

Uranium stocks:

None

Uranium prices:

There is no uranium market in Guyana.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	3 236	NA
Total	0	0	0	3 236	NA

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	3 236	NA
Total	0	0	0	3 236	NA

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Metasomatite	0	0	0	3 236
Total	0	0	0	3 236

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	2 947	NA
Total	0	0	0	2 947	NA

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	2 947	NA
Total	0	0	0	2 947	NA

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Metasomatite	0	0	0	2 947
Total	0	0	0	2 947

Hungary

Uranium exploration and mine development

Historical review

The first reconnaissance for uranium started in 1952 when, with Soviet participation, material from Hungarian coal deposits was checked for radioactivity. The results of this work led to a geophysical exploration programme (airborne and surface radiometry) in 1953 over the western part of the Mecsek Mountains. The discovery of the Mecsek deposit was made in 1954 and further work was aimed at the evaluation of the deposit and its development. The first shafts were excavated in 1955 and 1956 for the mining of sections I and II. In 1956, the Soviet-Hungarian uranium joint venture was dissolved and the project became the sole responsibility of the Hungarian state. That same year, uranium production began. Production began to decline in the late 80s and ended after 1998.

Recent and ongoing uranium exploration and mine development activities

The non-governmental mine development project, which started in 2007 with a focus on the area of the Mecsek deposit, is still in the environmental licensing phase. The Environmental Impact Study submitted at the end of 2017 is probably going to be modified regarding the planned production rate, following some legal actions and discussions with the environmental authority. If a licence is obtained, a mining property will be established and likely merged with the existing, historic mining properties in the area.

Uranium resources

Hungary's reported uranium resources are limited to those of the Mecsek deposit. The ore is hosted by Upper Permian sandstones with a thickness of up to 600 m. During Cretaceous time, the Permo-Triassic sandstones were folded into an anticline that makes up the framework structure of the Mecsek Mountains. The ore-bearing sandstone in the upper 200 m of the unit is underlain by a very thick Permian siltstone and covered by Lower Triassic sandstone. The thickness of the green-grey ore-bearing sandstone, locally referred to as the "productive complex", varies from 15 to 90 m. The ore minerals include uranium oxides and silicates associated with pyrite and marcasite.

Identified conventional resources (reasonably assured and inferred resources)

After the completion of the non-governmental exploration in the Mecsek Mountains in 2017, the Mining and Geological Survey of Hungary updated the in situ uranium resources of Hungary. As of 1 January 2021, the identified conventional resources amounted to a total of 22 230 in situ tU (16 673 recoverable tU) according to the Hungarian National Mineral Resource Inventory, a 23.9% increase compared to the amount reported in the previous four editions of the Red Book (note all are inferred resources; no reasonably assured resources [RAR] are reported).

Undiscovered conventional resources (prognosticated and speculative resources)

The updated prognosticated resources amount to a total of 14 845 in situ tU, a 10.6% increase compared to the amount reported in the previous four editions of the Red Book. These resources are tributary to the former Mecsek production centre. Speculative resources have not been estimated.

Uranium production

Historical review

The Mecsek underground mine and mill situated near the city of Pécs was the only uranium production centre in Hungary. Prior to 1 April 1992, it was operated by the state-owned Mecsek Ore Mining Company (MÉV). The mine began operation in 1956 and produced ore from a depth of 100 to 1 100 m until it was ultimately shut down in 1997. During operation, it produced about 500 000-600 000 tonnes ore/yr with an average mining recovery of 50-60%. The ore processing plant had a capacity of 1 300 to 2 000 tonnes ore/day and employed radiometric sorting, agitation acid leach (and alkaline heap leaching) with ion-exchange recovery. The nominal production capacity of the plant was about 700 tU/yr.

The Mecsek mine consisted of five sections with the following history:

- section I: operating from 1956 to 1971;
- section II: operating from 1956 to 1988;
- section III: operating from 1961 to 1993;
- section IV: operating from 1971 to 1997;
- section V: operating from 1988 to 1997.

The ore processing plant became operational in 1963. Prior to its operation, 1.2 million tonnes of unprocessed ore were shipped to the Sillimae metallurgy plant in Estonia. After 1963, processed uranium concentrates were shipped directly to the former Soviet Union.

Mining and milling operations were shut down at the end of 1997 because changes in market conditions made the operation uneconomic. Throughout its operational history, total production from the Mecsek mine and mill, including heap leaching, amounted to about 21 000 tU.

Status of production capability

Since the closure of the Mecsek mine in late 1997, the only production of uranium in Hungary has been as a by-product recovery of water treatment activities (see item (3) in the next paragraph), amounting to a total of about 2-6 tU/yr. During this reporting period 3-4 tU/yr were recovered. Section III of the historic mine workings below the water drainage horizon (formerly the main haulage adit) was completely flooded, and it is expected that Sections II-IV-V will be flooded by 2024.

Environmental activities and socio-cultural issues

Closure and large-scale site remediation activities at the Mecsek uranium production centre were carried out between 1998 and 2008. The remediation consisted of: (1) removing several hundred thousand tonnes of contaminated soil from various areas around the site to an on-site disposal facility, (2) remediation of tailing ponds and waste rock piles by the placement of isolating soil covers, and (3) abandonment and closure of underground mine workings, as well as groundwater extraction and treatment. Although the large-scale remediation programme was completed by the end of 2008, long-term care activities – such as groundwater remediation, environmental monitoring and maintenance of the engineered disposal systems – will likely need to continue for some years to come. In 2019, the soil cover of two abandoned waste rock dumps was improved by increasing its thickness to 1 m, and some areas with increased radiation were covered with an isolating soil layer. In addition, a new groundwater monitoring well has been installed, with another to be completed in 2021, and 5-6 historic exploration drill sites have been remediated.

Since July 2016, long-term care of Hungarian uranium mining and ore processing legacy sites is under the direct responsibility of the Mining Property Utilization Company in the Public Interest (www.bvh.hu). As the legal successor of the former Mecsek mine (a state-owned venture), it is responsible for paying compensation, including damages for occupational disease, income and pension supplements, reimbursements of certified costs and dependent expenses to people formerly engaged in uranium mining. Costs associated with the environmental remediation of the Mecsek mine are provided in the following table.

Costs of environmental management

(HUF thousands)

	Pre-1998	1998 to 2008	2009 to 2020
Closing of underground spaces	NA	2 343 050	W
Reclamation of surficial establishments and areas	NA	2 008 403	W
Reclamation of waste rock piles and their environment	NA	1 002 062	W
Reclamation of heap leaching piles and their environment	NA	1 898 967	W
Reclamation of tailings ponds and their environment	NA	8 236 914	W
Water treatment	NA	1 578 040	W
Reconstruction of electric network	NA	125 918	W
Reconstruction of water and sewage system	NA	100 043	W
Other infrastructural service	NA	518 002	W
Other activities including monitoring, staff, etc.	NA	2 245 217	W
Total	5 406 408	20 056 616	W

NA = Not available. W = Withheld.

After remediation of the uranium mining and ore processing legacy sites, the annual cost of long-term care activities amounts to some HUF 600-750 million.

Regulatory regime

In Hungary, the mining activity is supervised and the licences are issued by the Mining Authority, consisting of the Mining and Geological Survey of Hungary as top authority, and five regional offices integrated into the county government offices. There is no special regulation dedicated to uranium mining; the general mining law applies to uranium ore production. In the past, the regional mining offices granted uranium exploration and production licences. Currently, the only way to obtain a new uranium exploration or production right (concession) is through public tendering, provided that the government decides to start such a procedure. In addition to the mining licence or concession, a number of other licences have to be obtained, such as environmental and land utilisation licences.

The mining companies, including uranium ore producers, must have financial guarantees supported by detailed expense calculations to cover the mine closure and decommissioning costs. The guarantees are checked and monitored by the Mining Authority.

Uranium requirements

In January 2020, the government approved the new National Energy Strategy 2030 and the National Energy and Climate Plan, and opted for the long-term maintenance of nuclear in the energy mix. In 2020, the MVM Paks Nuclear Power Plant (Paks Nuclear Power Plant) generated 16 054 GWh electricity, which accounted for 48% of gross electricity generation and 35.6% of domestic electricity consumption. The 2020 Unit Capability Factor was as follows: Unit 1: 87.9%; Unit 2: 91.3%; Unit 3: 93.1%; Unit 4: 83.1%, giving an average for the plant of 90.9%.

The licensing procedure for the lifetime extension of the Paks nuclear power plant from 30 to 50 years has been fully completed. Regarding the two new units planned, the construction licence application was submitted to the Hungarian Atomic Energy Authority (HAEA) on 30 June 2020. The authority has 12 months to carry out the determination, with a possible extension of 3 months.

National policies relating to uranium

Since the shutdown of the Hungarian uranium mining industry in 1997, there have been no uranium-related policies. The Energy Mineral Resources Utilisation and Stock Management Action Plan summarises the available Hungarian uranium resources. It concludes that if uranium ore mining is profitable, the government should consider partnerships with private investors in mining, through state-owned companies. However, there is at present no government measure or action planned to facilitate mining.

Uranium stocks

The by-product ($UO_4 \cdot 2H_2O$) of the water treatment activities at the former uranium mining and ore processing site (see the environmental activities above) is stored at the mine water treatment facility until export. At the end of 2020, the inventory amounted to 9 473 kgU. No uranium was exported during the reporting period.

Uranium prices

Uranium prices are not available as they are commercially confidential.

Uranium exploration and development expenditures and drilling effort – domestic

(EUR)

	2018	2019	2020	2021 (expected)
Private* exploration expenditures	NA	NA	NA	NA
Government exploration expenditures	0	0	0	0
Private* development expenditures	NA	NA	NA	NA
Government development expenditures	0	0	0	0
Total expenditures	NA	NA	NA	NA

* Non-government.

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	0	22 230	75*
Total	0	0	0	22 230	75*

* Estimated.

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	0	22 230	75*
Total	0	0	0	22 230	75*

* Estimated.

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	0	22 230
Total	0	0	0	22 230

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	14 845

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Underground mining*	21 000	0	0	21 000	0
Co-product/by-product	83	3	3	89	3
Total	21 083	3	3	21 089	3

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	20 475	0	0	20 475	0
Heap leaching*	525	0	0	525	0
Other methods**	83	3	3	89	3
Total	21 083	3	3	21 089	3

* A subset of open-pit and underground mining since it is used in conjunction with them.

** Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	21 083	3	3	21 089	3
Total	21 083	3	3	21 089	3

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
3	100	0	0	0	0	0	0	3	100

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres	NA	NA	NA	NA
Employment directly related to uranium production	NA	NA	NA	NA

Net nuclear electricity generation (TWh net)

	2019	2020
Nuclear electricity generated (TWh net)	15.4	15.2

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
1 900	1 900	1 900	1 900	3 100	4 300	3 400	3 400	2 400	2 400

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
352	348	341	341	574	807	615	615	466	466

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	0	0	0	0	0
Producer	9	0	0	0	9
Utility	0	0	0	0	0
Total	9	0	0	0	9

India

Uranium exploration and mine development

Historical review

The history of exploration for atomic minerals, including uranium, in India dates back to the discovery of the occurrence of monazite-bearing black sand along the southern and south-western coast of India in 1909. The first report of uranium in India was in 1913 when an occurrence of gummite (altered uraninite) and a 36-pound pure uraninite nodule was discovered from a pegmatite at Bihar.

In India, exploration for uranium is carried out by the Atomic Minerals Directorate for Exploration and Research (AMD). The AMD emerged from a dedicated wing of the Survey of India (GSI) named the Rare Minerals Survey Unit (RMSU) created during the Second World War (1939-1945). Subsequently, after the promulgation of the Atomic Energy Act and the constitution of the Atomic Energy Commission (AEC) in 1948, the RMSU was brought under the AEC during 1949.

The first extensive surveys for uranium began in 1949 in the Singhbhum Shear Zone (SSZ) and the first exploratory drilling for uranium commenced in 1951 in Jaduguda in the SSZ. Until the mid-1970s, uranium exploration was mainly confined to uranium provinces in the SSZ, Jharkhand, and in the Umra-Udaisagar area in the Aravalli Fold Belt in Rajasthan, targeting vein-type mineralisation. This resulted in the discovery of 16 low-grade uranium deposits of varying sizes in the SSZ, Jharkhand, and one deposit at Umra, Rajasthan. Exploratory mining commenced in Jaduguda as well as in Umra in 1957. Seven out of the sixteen deposits in the SSZ are under exploitation. Exploration is currently being carried out in several sectors of the 200 km long SSZ, especially in the central and southern sectors.

The introduction of airborne surveys during the late 1950s was a boon to the exploration activities of AMD. India has been one of the pioneers in using airborne surveys for uranium exploration. AMD commenced airborne surveys in 1955 with an indigenously designed and developed total gamma-ray count system to cover large areas of the country.

Uranium exploration was expanded to other favourable geological domains, which resulted in establishing several small uranium deposits such as Bodal and Bhandaritola, Chhattisgarh, in Paleoproterozoic amphibolites; Jajawal, Chhattisgarh, in Paleoproterozoic sheared migmatites of the Chhotanagpur Granite Gneiss Complex; and Walkunji, Karnataka, in basal quartz-pebble conglomerates of the Dharwar Group.

During the mid-1970s, exploration targeted sandstone-type uranium deposits. The exploration for sandstone-type uranium mineralisation resulted in the discovery of a high-grade, medium-tonnage deposit at Domiasiat (Kylleng-Pyndengsohiong-Mawthabah) in the Cretaceous sandstones of the Meghalaya. Exploration in contiguous sectors has established several small uranium deposits.

During the mid-1980s, a low-grade, stratabound deposit hosted by dolostones of the Vempalle Formation was established at Tummalapalle, Andhra Pradesh, in the Proterozoic Cuddapah Basin. Since the dolostone ore was not amenable to conventional leaching procedures in vogue at that time, exploration in this sector was discontinued. However, the development of an economically viable alkali pressure leaching process rejuvenated the exploration activities in the Vempalle Formation along the southern part of the Cuddapah Basin, targeting carbonate-hosted uranium mineralisation. Intensive multi-parametric exploration carried out in Tummalapalle and adjacent sectors led to the identification of substantial uranium resources in the southern part of the Cuddapah Basin. The Tummalapalle uranium deposit is under exploitation.

During the early 1990s, a near-surface deposit was discovered adjacent to the unconformity contact between basement granites and the overlying Mesoproterozoic Srisailam Quartzite at Lambapur, Telangana (Andhra Pradesh). These occurrences were investigated and several exploration areas were subsequently identified. Favourable geological criteria and sustained exploration efforts resulted in establishing deposits at Peddagattu and Chitrial along the unconformity contact between the basement granites and overlying quartzites of the Srisailam Formation. Exploration in the adjacent Palnad Sub-basin identified a small deposit at Koppunuru. Exploration is continuing in the Palnad Sub-basin.

Sustained exploration in the North Delhi Fold Belt (NDFB), in parts of Rajasthan and Haryana, targeting metasomatic-type uranium mineralisation, led to the discovery of the Rohil uranium deposit, Rajasthan. Exploration is being carried out in various sectors of the ~200 km long "Albitite Line" in Rajasthan and Haryana. Intensive exploration in adjacent sectors of Rohil established another deposit in Jahaz, Rajasthan.

During the late 1990s, multi-parametric exploration in the Neoproterozoic Bhima Basin led to establishing a medium-grade and small tonnage uranium deposit in Gogi, Karnataka, hosted by brecciated limestone and granite along the Gogi-Kurlagare-Gundahalli fault located in the southern part of the basin. Sustained exploration in this geological domain has established another uranium deposit in Kanchankayi.

Starting in the 2010s, AMD identified substantial uranium resources. Exploration has been supported by state-of-the-art hydrostatic drilling rigs, analytical equipment, and the acquisition of high-resolution heliborne- and ground-based geophysical data over favourable geological domains in the country.

Recent and ongoing uranium exploration and mine development activities

In the past few years, exploration activities have been concentrated in the following areas:

- Proterozoic Cuddapah Basin, Andhra Pradesh and Telangana.
- Mesoproterozoic Singhbhum Shear Zone, Jharkhand.
- Mesoproterozoic North Delhi Fold Belt, Rajasthan and Haryana.
- Cretaceous Mahadek Basin, Meghalaya.
- Neoproterozoic Bhima Basin, Karnataka.
- Mesoproterozoic Kaladgi Basin, Karnataka.
- Mesozoic Satpura Gondwana Basin, Madhya Pradesh.
- Mesoproterozoic Chhotanagpur Granite Gneiss Complex, Uttar Pradesh, Madhya Pradesh and Jharkhand state.
- Cenozoic Siwalik Group, Himachal Pradesh.
- Proterozoic Aravalli Fold Belt, Rajasthan.
- Other geological domains with potential are under active exploration such as the: basement fractures surrounding the southern part of Cuddapah Basin, Andhra Pradesh; Shillong Basin, Assam; basement crystalline terrain, Arunachal Pradesh; Vindhyan, Bijawar and Chhattisgarh basins, Uttar Pradesh, Madhya Pradesh, and Chhattisgarh states; Kotri-Dongargarh belt, Chhattisgarh.
- Extensive exploration including ground and heliborne geophysical (ZTEM, TDEM, magnetic and radiometric), ground geological, radiometric and geochemical surveys, and drilling are planned in other geological domains of the country that have the potential to host uranium mineralisations.

Proterozoic Cuddapah Basin, Andhra Pradesh and Telangana

The Cuddapah Basin (Paleo- to Neoproterozoic) of the Dharwar Craton of Southern Peninsular India is one of the major uranium provinces hosting uranium mineralisation at various stratigraphic levels. Three types of uranium mineralisation/deposits have been identified in the Cuddapah Basin: carbonate-hosted stratabound-type, unconformity-related, and fracture-controlled.

- Carbonate uranium deposits

The southern part of the Cuddapah Basin hosts a unique, low-grade, and large-tonnage uranium deposit in the dolostones of the Vempalle Formation in the Tummalapalle-Rachakuntapalle sector. This formation occurs at the lower stratigraphic sequence of the Cuddapah Basin. Uranium mineralisation has been traced intermittently over a strike length of 160 km from Reddipalle in the north to Maddimadugu in the south-east. The vast extent of the deposit, its stratabound nature hosted by dolostone, and point-to-point correlation with uniform grade and thickness of the mineralisation over considerable lengths along the strike and dip, make the deposit unique. Two ore lodes with an average thickness of 2.30 m and 1.75 m, separated by a lean/unmineralised band of 3.0 m, are under active exploration at vertical depths of up to 825 m. Sustained exploration activities over the 16 km segment within the 160 km long belt have added substantial uranium resources. Intensive exploration in the eastern extension of the Tummalapalle-Rachakuntapalle sector has established another sizeable ore block, named Rachakunatapalle East. Exploration is continuing in several sectors of the 16 km long belt.

- Proterozoic unconformity uranium deposits

The north-western margin of the Cuddapah Basin, comprising the Meso- to Neoproterozoic Srisailam and Palnad Sub-Basins, are known for their potential for unconformity-related uranium deposits. Intensive exploration over the past few decades in the northern part of the Srisailam Sub-Basin had established three low-tonnage, low-grade uranium deposits named Lambapur, Peddagattu, and Chitrial (stratiform fracture-controlled deposit subtype). Exploration efforts along the northern margin of the Palnad Sub-basin have resulted in locating a low-grade and low-tonnage deposit at Koppunuru. Sustained exploration is being continued in potential sectors having a similar lithostructural setup around Sarangapalle, in the Palnad Sub-basin, to identify unconformity-related uranium mineralisation. Substantial dimensions of uranium mineralisation occurring close to the unconformity between the basement granite and Gulcheru quartzite have been established in the Kappatralla outlier.

- Sandstone, mafic dykes/sills in Proterozoic sandstone subtype uranium deposits

The Gulcheru quartzite of the Cuddapah Supergroup, overlying the basement granitoid in the southern parts of the Cuddapah Basin, are intensely fractured, faulted and intruded by east-west trending basic dykes. Uranium mineralisation is associated with the quartz-chlorite-breccia occurring along the contact between the Gulcheru quartzite and basic dykes. Furthermore, the fracture systems within the crystalline basement, proximal to the southern and eastern margins of the Cuddapah Basin, are known to host uranium mineralisation and are currently under exploration (e.g. Sivramapuram – Pincha and Kasturigattu). The fracture zones occurring within the Cuddapah Basin around the basement inlier at Ipuru are also being investigated.

Mesoproterozoic Singhbhum Shear Zone, Jharkhand

The Singhbhum Shear Zone (SSZ) is a 160 km long, arcuate belt of tectonised rocks fringing the northern boundary of the Singhbhum craton along the contact with the Singhbhum Group rocks. Exploration efforts since the early fifties led to the identification of several low-grade and low- to medium-tonnage uranium deposits, some of which are under active exploitation. The established uranium deposits are mainly located in the central and eastern sectors of the shear zone. Intensive exploration in various sectors in the SSZ has added significant resources to the uranium inventory. Notable among them are the Singridungri-Banadungri, Rajdah, Jaduguda North, Bangurdih and Narwapahar sectors. Intensive exploration is being carried out for the establishment of polymetallic mineralisation, including uranium in serpentinite of Proterozoic Iron Ore Group at Kudada, Jharkhand.

Mesoproterozoic North Delhi Fold Belt of Rajasthan and Haryana

The metasediments of the North Delhi Fold Belt, comprising the Khetri, Alwar, and Bayana-Lalsot Sub-Basins in the states of Rajasthan and Haryana, are the host to several uranium occurrences. The approximately 200 km long north-northeast to south-southwest NNE-SSW trending "Albitite Line" passing through the Delhi Supergroup and Banded Gneissic Complex is the site for extensive sodic metasomatism and holds great potential to host metasomatite-type uranium mineralisation. Integrated exploration including litho-structural, heliborne and ground geophysics and drilling resulted in the discovery of a fracture-controlled metasomatite-type uranium deposit near Rohil, Rajasthan. The entire "Albitite Line" holds immense potential for the discovery of additional uranium resources. Extensive ground and heliborne geophysical surveying and drilling has been carried out in several sectors along the "Albitite Line" for the delineation of metsomatite type uranium mineralisation. This has resulted in establishing a small tonnage uranium deposit at Jahaz, Rajasthan. Further, these exploration efforts have resulted in establishing promising new sectors in Gumansingh-Ki-Dhani, Narsinghpuri and Hurra-Ki-Dhani, in the contiguous area of Rohil, which have similar geological settings.

Cretaceous Mahadek Basin, Meghalaya

The Upper Cretaceous Lower Mahadek Formation, exposed along the southern margin of the Shillong plateau, Meghalaya, is a potential host for uranium mineralisation. This geological domain has been under exploration since the late 1970s. Substantial exploration over the years led to the discovery of seven low- to medium-grade, low- to medium-tonnage, uranium deposits at Domiasiat, Wahkyn, Wahkut, Gomaghat, Tyrnai, Umthongkut and Lostoin.

Neoproterozoic Bhima Basin, Karnataka

The Bhima Basin comprises calcareous sediments with minor arenaceous lithostratigraphic units of the Bhima Group, which were deposited over basement granite and have been affected by several east-west trending faults. A small-size, medium-grade uranium deposit has been established at Gogi along the Gogi-Kurlagare-Gundahalli fault. Intensive multi-parametric exploration also established another deposit at Kanchankayi, Karnataka, adjacent to the Gogi uranium deposit. Current exploration efforts are concentrated in the eastern extensions of the Kanchankayi sector, around Hulkal, along the north-eastern extensions of the Gogi uranium deposit.

Palaeozoic – Mesozoic Satpura Gondwana Basin, Madhya Pradesh

The Gondwana age sedimentary basins of India comprise a suitable environment for hosting sandstone-type uranium mineralisation. The lower Motur Formation of the Satpura Gondwana Basin of Central India has been identified as the potential geological domain for hosting sandstone-type uranium mineralisation. Extensive surface and subsurface exploration in the Motur Formation has delineated significant uranium mineralisation in the Dharangmau – Kachhar sector. Exploration is continuing in this geological domain.

Mesoproterozoic Kaladgi Basin, Karnataka

The east-west trending Meso-Neoproterozoic Kaladgi Basin is located on the north-western margin of the western Dharwar Craton. The unmetamorphosed sediments of the Kaladgi Supergroup overlie the basement granitoids and Chitradurga schists. The northern and western extensions of the basin are covered by the Deccan Traps. The basement is comprised of schist belts with slivers of graphite-bearing meta-pelites and granites with associated tectonism. Significant surface uranium mineralisation over a considerable extent hosted by arenites has been identified near Deshnur. Subsurface exploration in the western part of Kaladgi Basin led to the emergence of another prospective sector in the Suldhal-Gujanal-Malarmardi area, where uranium mineralisation is hosted by the lower conglomerate, basal arenite and basement schist close to the unconformity.

Mesoproterozoic Chhotanagpur Granite Gneissic Complex (CGGC), Uttar Pradesh, Madhya Pradesh and Jharkhand

The Chhotanagpur Granite Gneiss Complex (CGGC) forms part of the prominent Mesoproterozoic linear mobile belt in East and Central India lying between the Narmada-Son-Brahmaputra lineaments designated as the "Central Indian Tectonic Zone" (CITZ) in the North and the Central Indian Suture (CIS) to the south. The CGGC hosts a thick pile of arkosic to psammo-pelitic metasediments that has undergone multiple phases of tectonic, plutonic, thermal and metamorphic events, which resulted in the extensive development of migmatites. The exposed rocks include banded gneisses and metasedimentary enclaves, overlain by the Mahakoshal supracrustals and sediments of the Vindhyan Supergroup in the north and Gondwana Supergroup in the south. Uranium mineralisation within migmatites is hosted by varied lithological units spread over a large area (350 km^2) in the Son valley crystallines, in the north-western part of the CGGC. Intensive exploration is being carried out in potential blocks at Naktu, Kudar, Kudri, Jhapar, Kurludih and Anjangira, where the host rock is essentially an albite-rich pegmatoid leucosome mobilizate (PLM).

Cenozoic Siwalik Basin, Himachal Pradesh

The Siwalik Group constitutes a thick sequence of molasse deposits laid down in a long narrow fore-deep, formed to the south of the rising Himalayas during the Middle Miocene to the Pleistocene. The sediments are traceable in India from Jammu in the west to the Brahmaputra valley in the east. Multi-parametric exploration has helped in identifying numerous uranium occurrences spread over the entire Siwalik belt between Poonch (Jammu and Kashmir) in the west and Tanakpur (Uttar Pradesh) in the east. More than 350 uranium occurrences forming eight major clusters have been identified. The majority of these occurrences are confined to three distinct stratigraphic horizons: 1) lower part of Upper Siwaliks; 2) upper part of Middle Siwaliks; and 3) upper part of Lower Siwaliks. The important uranium zones identified are: 1) Maler in Jammu and Kashmir; 2) Astotha-Khya-Loharian; 3) Galot-Andalada–Sibal-Loharkar; 4) Rajpura-Polian; 5) Romehra in Himachal Pradesh; 6) Morni-Nathai in Haryana; 7) Naugajiya Rao-Sanbarsot-Sakhumbari Rao; and 8) Kathaul-Danaur-Kholgarh in Uttar Pradesh. Among these, the Rajpura-Polian and Sibal-Loharkar sectors, Himachal Pradesh, where uranium mineralisation is hosted by sediments of the upper part of Middle Siwalik, are under active exploration.

Proterozoic Aravalli Fold Belt, Rajasthan

The Aravalli Supergroup (ASG) occupies the eastern part of the Aravalli Mountain Range from Nathdwara in the north to Champaner in the south over a distance of approximately 350 km with a width varying from 40 km to 150 km. It has an arcuate form with a northeast-southwest trend in the north, north-south in Udaipur and northwest-southeast in the south. The ASG can be divided into two distinct sedimentary facies: (1) the shelf facies, comprising mafic volcanic, coarse clastics and carbonates accumulated in the epicontinental sea along the pericontinental slope, and (2) the carbonate-free deep-sea facies, comprising dominantly metapelites with bands of quartzite. The ASG has undergone polyphase deformation and witnessed three main events of magmatism. The Aravalli Fold Belt is known for its uranium metallogeny of different styles among which uranium mineralisation associated with carbon phyllite is the most promising. Several anomalies have been located at the Umra, Udaisagar, Kalamagra, Haldughati, Sukher, Oda-Kevda and Undwala areas. Multi-parametric exploration is ongoing in the Umra area.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

India's known conventional in situ uranium resources (reasonably assured resources and inferred) are estimated to be 292 867 tU (in situ) hosted in the following deposit types:

Deposit type	In situ resource (tU)	Proportion of deposits
Carbonate	163 655 tU	56%
Metamorphite	72 615 tU	25%
Sandstone	20 528 tU	7%
Proterozoic Unconformity	18 072 tU	6%
Metasomatic	11 804 tU	4%
Granite-related	5 841 tU	2%
Paleo-quartz-pebble-conglomerate	352 tU	<1%
Total	292 867 tU	100%

As of 1 January 2021, the known conventional in situ resources include 282 401 tU of reasonably assured resources (RAR) and 10 466 tU of inferred resources (IR). This amounts to a substantial increase in RAR, compared to what was reported for the Red Book 2020. These changes are mainly due to appreciable resource additions in the contiguous area of the stratabound deposit in the southern part of the Cuddapah Basin and the extension areas of known deposits in the Singhbhum Shear Zone, Bhima Basin and North Delhi Fold Belt.

Undiscovered conventional resources (prognosticated and speculative resources)

In parts of Andhra Pradesh, Meghalaya, Rajasthan, Jharkhand and Karnataka, potential areas for uranium resources were re-evaluated with a higher degree of confidence. As of 1 January 2021, undiscovered resource estimates increased to 144 160 tU under the prognosticated category and 55 360 tU under the speculative category, both as in situ resources.

The increase in the prognosticated resources category from 127 200 tU in 2019 to 144 160 tU in 2021 is mainly due to the greater degree of confidence obtained by carrying out multidisciplinary exploration in some of the potential geological domains, such as the Southern Cuddapah Basin, Andhra Pradesh; Singhbhum Shear Zone, Jharkhand, and Bhima Basin, Karnataka; North Delhi Fold Belt, Rajasthan; Satpura Gondwana Basin, Madhya Pradesh; Chhotanagpur Granite Gneiss Complex, Uttar Pradesh; Madhya Pradesh and Jharkhand and Siwalik Group, Himachal Pradesh.

Similarly, the increase in the speculative resources category from 55 120 tU in 2019 to 59 360 tU in 2021 is mainly due to the identification of potential exploration targets in several geological domains, namely: Satpura Gondwana basin, Madhya Pradesh; Proterozoic basins such as Vindhyan, Bijawar, Chhattisgarh and Shillong Basins, Madhya Pradesh, Chhattisgarh, Assam and Meghalaya; Kaladgi Basin, Karnataka; Aravalli Fold Belt, Rajasthan, etc.

Uranium production

Historical review

The Uranium Corporation of India Ltd (UCIL) was formed in October 1967 under the administrative control of the Department of Atomic Energy, Government of India. The UCIL operates six underground uranium mines (Jaduguda, Bhatin, Narwapahar, Turamdih, Bagjata, and Mohuldih) and one open-pit mine (Banduhurang in Singhbhum East district of Jharkhand state). The ore produced from the mines is processed in two processing plants located at Jaduguda and Turamdih.

All of these facilities are located in a multi-metal mineralised sector – the Singhbhum Shear Zone in the eastern part of India. In addition to these, UCIL has also constructed a uranium mine and a processing plant in the YSR district (formerly Kadapa) of Andhra Pradesh.

Status of production facilities, production capability, recent and ongoing activities and other issues

The total installed capacity of UCIL's three operating production plants is as follows:

- Jaduguda Plant: 2 500 t ore/day;
- Turamdih Plant: 3 000 t ore/day;
- Tummalapalle Plant: 3 000 t ore/day.

Recent and ongoing activities

Jaduguda mine

The Jaduguda uranium deposit lies within the metasediments of the Singhbhum Shear Zone. The host rocks are of Proterozoic age. There are two prominent parallel ore lenses: the Footwall lode (FWL) and the Hangingwall lode (HWL). These lodes are separated by a 100 m barren zone. The FWL extends over a strike length of about 600 m in a south-east to north-west direction. The strike length of HWL is about 250 m and is confined to the eastern part of the deposit. Both the lodes have an average dip of 40 degrees towards the north-east. Of the two lodes, the FWL is better mineralised. The Jaduguda deposit has been explored up to a depth of 880 m.

Entry to the mine is through a 640 m deep vertical shaft. An underground auxiliary vertical shaft, sunk from 555 m to 905 m, provides access to deeper levels. The cut-and-fill stoping method is practised, giving about 80% ore recovery. De-slimed mill tailings are used as backfill material. Ore is hoisted by the skip in stages through shafts to surface and sent to the Jaduguda mill by conveyor for further processing.

Bhatin mine

The Bhatin uranium deposit is located 4 km north-west of Jaduguda. A major strike-slip fault lies between the Jaduguda and Bhatin deposits. Both of the deposits lie in similar geological settings. The Bhatin mine began production in 1986. The ore lens has a thickness of 2 to 10 m with an average dip of 35 degrees and entry to the mine is through an adit, with deeper levels accessed by inclines. Cut-and-fill stoping is practised and deslimed mill tailings from the Jaduguda mill are used as backfill. Broken ore is trucked to the Jaduguda mill. UCIL has planned for increasing underground productivity of this mine by further mechanising its working methods.

Narwapahar mine

The Narwapahar deposit (about 12 km west of Jaduguda) has been operating since 1995. In this deposit, discrete uraninite grains occur within chlorite-quartz schist with associated magnetite, with several lenticular-shaped ore lenses extending over a strike length of about 2 100 m, each with an average north-easterly dip of 30 to 40 degrees. The thickness of the individual ore lenses varies from 2.5 to 20 m. The deposit is accessed by a 355 metre-deep vertical shaft and a 7-degree decline from the surface. Cut-and-fill stoping is also practised using deslimed mill tailings of the Jaduguda plant as backfill. Ore is trucked to the Jaduguda plant for processing.

Turamdih mine

The Turamdih deposit is located about 12 km west of Narwapahar. Discrete uraninite grains within feldspathic-chlorite schist form a series of ore lenses with a very erratic configuration. The mine was commissioned in 2003 and three levels (70 m, 100 m, and 140 m depth) have been accessed through an 8-degree decline from the surface and a vertical shaft has been sunk to provide access to deeper levels. Ore from this mine is processed at the Turamdih plant. Cut-and-fill stoping is also practised using deslimed mill tailings of the Turamdih plant. Considering the ore geometry, possibilities of adopting sub-level stoping methods in specific segments of the orebody are being explored with higher productivity. Trial stoping in one such area has been undertaken.

Bagjata mine

The Bagjata deposit, situated about 26 km east of Jaduguda, has been developed as an underground mine with a 7-degree decline for entry and a vertical shaft to access deeper levels. This mine was commissioned in 2008. Ore from the Bagjata mine is transported by road to the Jaduguda plant for processing. Cut-and-fill stoping is practised in the Bagjata mine and deslimed mill tailings from the Jaduguda mill are used as backfill.

Banduhurang mine

The Banduhurang deposit has been developed as a large opencast mine. The orebody is the western extension of ore lenses at Turamdih. The mine was commissioned in 2009 and ore is transported by road to the Turamdih plant for processing.

Mohuldih mine

The deposit is located in the Seraikela-Kharswan district of Jharkhand, about 2.5 km west of Banduhurang. The mine was commissioned in 2012. The ore from the mine is treated at the Turamdih plant.

Tummalapalle mine

Hosted in carbonate rock, this deposit is located in the YSR district (formerly Kadapa) of Andhra Pradesh. It is the first uranium production centre in the country located outside Jharkhand. This underground mine is accessible by three declines along the apparent dip of the orebody. The central decline is equipped with a conveyor for ore transport and the other two declines are used as service paths. The ore is treated in the plant adjacent to the mine at Tummalapalle. The expansion of the mine and processing plant at Tummalapalle has been planned to augment uranium production.

Jaduguda mill

Ore produced at the Jaduguda, Bhatin, Narwapahar and Bagjata mines is processed in the mill located at Jaduguda. Commissioned in 1968, the mill is capable of treating about 2 500 t/day of dry ore. Following crushing and grinding to 60% (passing 200 mesh), the ore is leached in pachuca tanks using sulphuric acid under controlled pH and temperature. After filtration of the pulp, ion-exchange resin is used to recover the uranium. After elution, the product is precipitated using hydrogen peroxide to produce uranium peroxide as a final product containing about 88% U_3O_8. The treatment of mine water and reclaiming tailings water has resulted in reduced freshwater requirements, as well as increasing the purity of the final effluent. A magnetite recovery plant is also in operation at Jaduguda producing very fine-grained magnetite as a by-product.

Turamdih mill

Uranium ore from the Turamdih and Banduhurang mines is being processed in the Turamdih mill. The mill, commissioned in 2009, is capable of treating about 3 000 t/day dry ore. The plant adopts similar processing technology as that of Jaduguda. Presently, this plant produces magnesium diuranate as the final product. Plans to produce uranium peroxide as the final product is under implementation. This plant is being expanded to process 4 500 t/day dry ore.

Tummalapalle mill

The uranium processing plant at Tummalapalle in the YSR district (formerly Kadapa) of Andhra Pradesh is based on indigenously developed alkali leaching (under high temperature and pressure) technology. The plant was put into regular operation in January 2017 to process 3 000 t/day ore. The expansion of this plant to process 4 500 t/day ore has also been planned.

Uranium production centre technical details

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5	Centre #6	Centre #7	Centre #8
Name of production centre	Jaduguda	Bhatin	Narwapahar	Bagjata	Turamdih	Banduhurang	Mohuldih	Tummalapalle
Production centre classification	Existing	Existing	Existing	Existing	Existing	Existing	Existing	Existing
Start-up date	1967	1986	1995	2008	2003	2007	2011	2017
Source of ore:	Uranium ore	Uranium ore	Uranium ore	Uranium ore	Uranium ore	Uranium ore	Uranium ore	Uranium ore
Deposit name(s)	Jaduguda	Bhatin	Narwapahar	Bagjata	Turamdih	Banduhurang	Mohuldih	Tummalapalle
Deposit type(s)	Metamorphite	Metamorphite	Metamorphite	Metamorphite	Metamorph.	Metamorphite	Metamorphite	Carbonate (Strata bound)
Resources (tU)	-	-	-	-	-	-	-	-
Grade (% U)	-	-	-	-	-	-	-	-
Mining operation:								
Type (OP/UG/ISL)	UG	UG	UG	UG	UG	OP	UG	UG
Size (tonnes ore/day)	650	150	1 500	500	750	3 500	500	3 000 (4 500 planned)
Average mining recovery (%)	80	75	80	80	75	65	80	60
Processing plant:	Jaduguda				Turamdih			Tummalapalle
Type (IX/SX/AL)	IX/AL				IX/AL			ALKPL*
Size (tonnes ore/day)	2 500				3 000			3 000
Average process recovery (%)	80				78			70
Nominal production capacity (tU/year)	200				190			211
Plans for expansion	-				Turamdih mine (1 000 TPD) and Turamdih plant (4 500 TPD) are under expansion			Tummalapalle mine (4 500 TPD) and Tummalapalle plant (4 500 TPD) are under expansion
Other remarks	Ore being processed in Jaduguda plant				Ore being processed in Turamdih plant			

* Pressurised alkali leach. TPD = tonnes per day.

Uranium production centre technical details *(cont'd)*

(as of 1 January 2021)

	Centre # 9	Centre # 10	Centre # 11
Name of production centre	Gogi	Lambapur-Peddagattu	Kylleng-Pyndengsohiong Mawthabah (KPM)
Production centre classification	Planned	Planned	Planned
Start-up date	2024	2024	2028
Source of ore:	Uranium ore	Uranium ore	Uranium ore
Deposit name(s)	Gogi	Lambapur-Peddagattu	KPM
Deposit type(s)	Granite-related	Unconformity	Sandstone
Resources (tU)	-	-	-
Grade (% U)	-	-	-
Mining operation:			
Type (OP/UG/ISL)	UG	UG/OP	OP
Size (tonnes ore/day)	500	1 250	2 000 (250 days/yr working)
Average mining recovery (%)	60	75	90
Processing plant:	Gogi	Seripally	KPM
Type (IX/SX/AL)	AL	IX/AL	IX/AL
Size (tonnes ore/day)	500	1 250	2 000 (275 days/yr working)
Average processing ore recovery (%)	88	77	87
Nominal production capacity (tU/year)	130	130	340
Plans for expansion	-	-	-
Other remarks	Ore to be processed in the plant at Saidapur	Ore to be processed in the plant at Seripally	

Ownership structure of the uranium industry

In India, uranium prospecting/exploration and mining are carried out exclusively by the central government. The uranium industry is wholly owned by the Department of Atomic Energy, Government of India. The Atomic Minerals Directorate for Exploration and Research under the Department of Atomic Energy is responsible for uranium exploration programmes in India. Following the discovery and deposit delineation, the economic viability is evaluated. The evaluation stage may also include exploratory mining. Once a deposit of sufficient tonnage and grade is established, UCIL initiates activities for commercial mining and production of uranium concentrates.

Employment in the uranium industry

About 5 000 people are engaged in uranium mining and milling activities.

Future production centres

The uranium deposit located at Gogi in the Yadgir (former name Gulbarga) district, Karnataka, is planned for development as an underground mine. Exploratory mining work is in progress to establish the configuration of the orebody. The plant at Gogi will utilise alkali leaching technology.

A sandstone uranium deposit in the north-eastern part of the country at Kylleng-Pyndengsohiong, Mawthabah (formerly Domiasiat) in West Khasi Hills District, Meghalaya State, is planned for development by open-pit mining, with a processing plant to be situated near the mine.

Uranium deposits located at Lambapur-Peddagattu in the Nalgonda district, Andhra Pradesh, are also slated for development, with an open-pit and three underground mines proposed. An ore processing plant is being proposed at Seripally, 50 km from the mine site. Pre-project activities are in progress.

Environmental activities and socio-cultural issues

There are no environmental issues related to the existing uranium mines and processing plants operated by UCIL. However, provisions are made for the management of environmental impacts. The organisation responsible for this task is the Health Physics Group of the Bhabha Atomic Research Centre, located in Mumbai. It carries out environmental health monitoring for radiation, radon and dust at uranium production facilities. The Health Physics Unit operates the Environmental Survey Laboratory at Jaduguda and has establishments at all operating facilities.

Regulatory regime

In India, all nuclear activities, including mining of uranium or other atomic minerals, fall within the purview of the central government and are governed by the Atomic Energy Act, 1962 (AE Act) and regulations made thereunder. The Department of Atomic Energy (DAE) oversees the development and mining of uranium and other atomic minerals. Accordingly, policies of the DAE and provisions of the AE Act and regulations framed thereunder play a key role in the prospecting, exploration and mining of uranium. The exploration and mining of uranium are governed under the provisions of the Mines Act, 1952 and Mines and Minerals (Development and Regulation) Act, 1957 as well as rules made thereunder i.e. Atomic Minerals Concession Rules (AMCR), 2016 and Mineral Conservation and Development Rules (MCDR), 2017. In addition, all mining activities must comply with environmental regulations. The mining, milling and processing of uranium ore require a licence under the AE Act. The Atomic Energy Radiation Protection Rules (2004) and the Atomic Energy Working of Mines and Minerals and Handling of Prescribed Substances Rules (1984) provide procedural details for obtaining a licence and specify conditions required to carry out these activities.

A mining lease for uranium is granted by the state government after the mining plan is approved by the Atomic Minerals Directorate for Exploration and Research as per the provisions of the MMDR Act. The Atomic Energy Regulatory Board (AERB), an independent authority, regulates the safety and other regulatory provisions under the AE Act and ensures the safety of workers, the public and the environment. The AERB oversees various aspects of a mining plan that are required to conform to radiological safety, siting of the mill, disposal of tailings and other waste rocks, as well as decommissioning the facility. The opening, operating and decommissioning of uranium mines require compliance with the provisions under different legislation and regulations.

Uranium requirements

As of 1 January 2021, the total installed nuclear capacity in India was 6 780 MWe (gross), which is comprised of 18 pressurised heavy water reactors, two boiling water reactors and two light-water reactors.

Construction/commissioning of four pressurised heavy water reactors (KAPP 3 and 4: 2 x 700 MWe and Rajasthan Atomic Power Station 7 and 8: 2 x 700 MWe), and one prototype fast breeder (500 MWe) is in progress.

Annual uranium requirements in 2020 amounted to about 1 350 tU and this would increase in tandem with increases in installed nuclear capacity. Identified conventional uranium resources are sufficient to support 10-15 GWe installed capacity of pressurised heavy water reactors operating at a lifetime capacity factor of 80% for 40 years.

With international co-operation in peaceful nuclear energy, installed nuclear generating capacity is expected to grow significantly as more international projects are envisaged. However, the exact size of the programme based on technical co-operation with other countries is yet to be finalised.

Supply and procurement strategy

Uranium requirements for pressurised heavy water reactors are being met with a combination of domestic and imported sources. Two operating boiling water reactors and two light-water reactors of VVER-type require enriched uranium and are fuelled by imported uranium. Future light-water reactors will also be fuelled by imported uranium.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Uranium exploration, mining, production, fuel fabrication and the operation of nuclear power reactors are controlled by the government of India. National policies relating to uranium are governed by the Atomic Energy Act 1962 and the provisions made thereunder.

Imported light-water reactors to be built in the future will be purchased with an assured fuel supply for the lifetime of the reactor.

Uranium exploration and development expenditures and drilling effort – domestic

(Indian rupee millions)

	2018	2019	2020	2021 (expected)
Government exploration expenditures	4 186	4 570	3 616	4 792
Total expenditures	4 186	4 570	3 616	4 792
Government exploration drilling (m)	250 808	278 732	195 308	279 250
Total drilling (m)	250 808	278 732	195 308	279 250

* Non-government.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Underground mining (UG)	NA	NA	NA	259 260
Open-pit mining (OP)	NA	NA	NA	23 141
Total	NA	NA	NA	282 401

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Conventional from UG	NA	NA	NA	259 260
Conventional from OP	NA	NA	NA	23 141
Total	NA	NA	NA	282 401

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Proterozoic unconformity	NA	NA	NA	18 072
Sandstone	NA	NA	NA	17 638
Granite-related	NA	NA	NA	5 841
Metamorphite	NA	NA	NA	66 057
Metasomatic	NA	NA	NA	11 138
Carbonate	NA	NA	NA	163 655
Total	NA	NA	NA	282 401

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Underground mining (UG)	NA	NA	NA	8 372
Open-pit mining (OP)	NA	NA	NA	2 094
Total	NA	NA	NA	10 466

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Conventional from UG	NA	NA	NA	8 372
Conventional from OP	NA	NA	NA	2 094
Total	NA	NA	NA	10 466

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Sandstone	NA	NA	NA	2 890
Paleo quartz-pebble-conglomerate	NA	NA	NA	352
Metamorphite	NA	NA	NA	6 558
Metasomatic	NA	NA	NA	666
Total	NA	NA	NA	10 466

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	Cost range unassigned
NA	NA	144 160

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	59 360

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
NA	100	NA	NA	NA	NA	NA	NA	NA	100

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres	4 629	4 672	4 630*	4 600*
Employment directly related to uranium production	NA	NA	NA	NA

* Secretariat estimate.

Mid-term production projection (tonnes U/year)

2021	2022	2025	2030	2035	2040
NA	NA	NA	NA	NA	NA

Mid-term production capability (tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA				NA			

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA				NA			

Net nuclear electricity generation

	2019	2020
Nuclear electricity generated (TWh net)	39.05	45.16

Installed nuclear generating capacity to 2040

(MWe gross)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
6 780	6 780	NA	NA	NA	NA	NA	NA	NA	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
1 350	1 350	NA	NA	NA	NA	NA	NA	NA	NA

Indonesia

Uranium exploration and mine development

Historical review

Three uranium deposit localities have been identified in Indonesia. The West Kalimantan uranium deposits (Kalan deposits) were discovered in 1973. The North Sumatra uranium deposits (Sibolga deposits) were discovered in 1980. And the West Sulawesi uranium deposits (Mamuju deposits) were discovered in 2013. From 1981 to 1991, pilot-scale mining and processing experiments were carried out at the Kalan deposit with a plant capacity of two tonnes of ore per day. The pilot test of 964 tonnes of ore (1 000 ppm) yielded 740.5 kg of yellowcake (U in yellowcake 60%) via solvent extraction. Environmental remediation of the plant site is ongoing (2020). The Kalan metamorphite deposit type uranium mineralisation consists of uraninite (tourmaline-sulphide association) in veins in schistose metapelites, metasiltstones and quartzites derived from a Cretaceous protolith, with thermal metamorphism associated with the intrusion of younger granites. Centimetre to decimetre scale uranium mineralised veins exhibit lithological controls with mineralisation mobilised along schistosity planes, and tectonic controls where mineralisation on schistosity planes has been remobilised into open, cross-cutting younger faults and breccias. Mineralised intersections range up to 1.4 m in thickness with a maximum grade of up to 0.28% U from the Kalan test mining tunnel. The Mamuju deposits occur in Tertiary alkaline volcanic rocks. The Sibolga deposits occur in Tertiary sandstones with uranium enrichments associated with black shales.

Uranium exploration by the Centre for Development of Nuclear Ore and Geology of the National Nuclear Energy Agency of Indonesia (BATAN) started in the 1960s. Up to 1996, reconnaissance surveys had covered 79% of a total of 533 000 km^2 identified for surveying based on favourable geological criteria and promising exploration results. Since that year, the exploration activities have been focused on the Kalan, Kalimantan, in which the most significant indications of uranium mineralisation have been found. During 1998-1999, exploration consisted of systematic geological and radiometric mapping, including a radon survey carried out at Tanah Merah and Mentawa, Kalimantan to delineate the mineralised zone. The results of those activities increased speculative resource estimates by 4 090 tU to 12 481 tU. From 2000 up to 2002, exploration drilling was carried out at upper Rirang (178 m), Rabau (115 m) and Tanah Merah (181 m) in West Kalimantan.

In 2003-2004, additional exploration drilling was conducted at Jumbang 1 (186 m) and Jumbang 2 (227 m). In 2005, exploration drilling was carried out at Jumbang 3 (45 m) and at Mentawa (45 m), in 2006 at Semut (454 m) and Mentawa (45 m) and in 2007 at Semut (174 m). In 2008, no exploration drilling was undertaken.

In 2009, exploration drilling was continued in the Kalan Area and detailed, systematic prospection in the Kawat area and its surroundings was also carried out. General prospection in Bangka Belitung Province was also undertaken. Plans were adopted to extend exploration in Kalimantan and Sumatra by prospecting from general reconnaissance to systematic stages to discover new uranium deposits. In 2010, efforts were devoted to evaluating drilling data from the Kawat sector to re-evaluate estimates of speculative resources.

Uranium and thorium exploration in 2015 continued in the Mamuju area, West Sulawesi Province (alkaline volcanic-hosted mineralisation), and in the Ella Ilir area, West Kalimantan Province. In the Mamuju area, detailed ground radiometric mapping was conducted in the Takandeang, Taan, Ahu, Pangasaan and Hulu Mamuju sectors. Geophysical resistivity and induced polarisation surveys conducted in the Botteng and Takandeang sectors were followed by reconnaissance drilling for a total depth of 1 600 m, which was comprised of 570 m in the Botteng sector, 830 m in the Takandeang sector, and 200 m in the Taan sector. Drilling targets were anomalous uranium occurring as stratabound and supergene enrichment in volcanic deposits. Exploration in the Ella Ilir area included geological and radiometric mapping and reconnaissance drilling with 400 m of total depth. The drilling in this area focused on uranium veins in metapelite schistose and metatuff.

Recent and ongoing uranium exploration and mine development activities

In 2019, exploration was conducted in the Mamuju (West Sulawesi), Harau (West Sumatra), and Melawi (West Kalimantan) regions. Exploration in the Mamuju region was completed over the Ampalas, Takandeang, and Ahu sectors that are host to uranium and thorium anomalies. In the Ampalas area, geological and radiometric mapping was conducted in the upper part of Ampalas River, leading to the discovery of secondary uranium minerals in stratified volcanic rocks. In the Takandeang-Ahu area, six holes (425 m) were drilled to test for mineralisation in alkaline lava flows. In the eastern part of the Takandeang area, detailed geological mapping of lateritic soil was completed to understand uranium and thorium deposit characteristics and distribution. Geophysical investigation using resistivity methods identified soil thickness and bedrock morphology. Exploration in the Harau region focused on the re-evaluation of the previous discovery of anomalous radiometric values in the area. Based on the survey, thorium is contained in metamorphic rocks with very low contents of uranium. In Melawi region reconnaissance, geological, geochemical and radiometric mapping, as well as radon gas measurement focused on evaluating the potential for the occurrence of uranium deposits in a sedimentary basin setting.

In 2020, exploration was conducted in the Mamujui, Bangka Island and Melawi regions. In Mamuju, radon gas surveys were conducted over the 2019 Takandeang-Ahu drilling area to delineate the distribution of uranium. The geochemistry of drill core (by portable XRF) and associated spectrometric logging was also completed. In the Melawi basin, exploration included preliminary grid-based radon gas surveys leading to the identification of several radon anomalies that warrant further drill testing. Exploration in the Bangka Island area included detailed radiometric and radon gas surveys and spectral logging measurements in 13 holes (20-70 m depth) that tested a placer deposit.

No mining activity is currently under consideration.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

In situ measured and indicated resources amount to 7 391 tU (<USD 130/KgU), and the total in situ inferred resources are 4 065 tU (<USD 130/KgU). Inferred resources include those from the following localities: Mamuju (2 998 tU); Tann (431 tU); Takandeang including Salumati (165 tU) and Rantedunia (56 tU); Aloban including Sibolga (415 tU).

The Kalan Area consists of 16 sectors exhibiting uranium potential: Remaja, Lembah Hitam, Lemajung, Semut, Rirang, Rabau Hulu, Sarana, Tanah Merah, Amir Engkala, Jeronang, Jumbang, Ketungau, Parembang Kanan, Ririt, Dendang Arai, Bubu and Kayu Ara. Until 2018, Indonesia had reported 2 029 tU as a measured resource from the Remaja and Lembah Hitam Sector to the Red Book. A recent (2020) geostatistical evaluation of the Rabau Hulu sector completed by BATAN provided an estimate of 408 480 tonnes of ore with a grade of 0.0677% or 677 ppm uranium, for a total of 268 tU, including 214 tU categorised as a measured resource and 54 tU categorised as an indicated resource.

Undiscovered conventional resources (prognosticated and speculative resources)

Total undiscovered prognosticated and speculative resources amount to 37 292 tU. The undiscovered resources as prognosticated resources from the Kalan, Kawat, Mentawa and Mamuju areas are 30 179 tU. Additions to the speculative resources for the Mamuju area include the Hulu Mamuju Sector in 2019 (1 096 tU) and Ampalas Sector in 2020 (6 017 tU). The Hulu Mamuju resources were calculated using the United States Energy Research and Developments Administration method, while the Ampalas resources used the Three-Part Quantitative Assessment method.

Unconventional resources and other materials

The uranium resource potential in the Bangka and Belitung areas comprises placer deposits of monazite within a tin deposit. Monazite, a uranium/thorium phosphate mineral, was deposited in the alluvium and has mostly accumulated as a tailings by-product material of tin mining. The total resources from deposits in Bangka and Belitung islands total 25 236 tU. In Singkep, the uranium potential is in lateritic soil, with a resource of 1 100 tU. In Semelangan (West Kalimantan), uranium is present in bauxite lateritic deposits with resources of 624 tU. In Katingan (Central Kalimantan), monazite is present as a by-product material of zircon mining, with resources of 485 tU. Total unconventional resources are 27 445 tU.

Uranium exploration and development expenditures and drilling effort – domestic

(Indonesian rupiah [IDR])

	2018	2019	2020	2021 (expected)
Government exploration expenditures	1 165 110 957	3 483 091 000	598 560 000	354 396 000
Total expenditures	1 165 110 957	3 483 091 000	598 560 000	354 396 000
Government exploration drilling (m)	0	425	0	0
Government exploration holes drilled	0	6	0	0
Total drilling (m)	0	425	0	0
Total number of holes drilled	0	6	0	0

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	2 029	7 391	7 391	75
Total	0	2 029	7 391	7 391	75

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	2 029	7 391	7 391	75
Total	0	2 029	7 391	7 391	75

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Metamorphite	0	2 029	7 391	7 391
Total	0	2 029	7 391	7 391

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	2 998	2 998	75
Unspecified	0	0	1 067	1 067	75
Total	0	0	4 065	4 065	75

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	2 998	2 998	75
Unspecified	0	0	1 067	1 067	75
Total	0	0	4 065	4 065	75

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	415	415
Metamorphite	0	0	2 998	2 998
Volcanic-related	0	0	652	652
Total	0	0	4 065	4 065

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	37 292

Iran (Islamic Republic of)*

Uranium exploration and mine development

Historical review

Exploration

In 1935, the first occurrence of radioactive minerals was detected in the Anarak mining region. In 1959 and 1960, through co-operation between the Geologic Survey of Iran (GSI) and a French company, preliminary studies were carried out in Anarak and Khorassan (central Iran and Azarbaijan regions) to evaluate the uranium mineralisation potential.

Systematic uranium exploration in Iran began in the early 1970s to provide uranium ore for planned processing facilities. Between 1977 and the end of 1978, airborne geophysical surveys covered one-third of Iran (650 000 km²). Many surficial radiation anomalies were identified, and follow-up field surveys have continued to the present. The airborne coverage has been mainly over the central, south-eastern, eastern and north-western parts of Iran. The favourable regions studied by this procedure are the Bafq-Robateh Posht e Badam region (Saghand, Narigan, Khoshumi), Maksan and Hudian in south-eastern Iran and Dechan, Mianeh and Guvarchin in Azarbaijan. Outside of the airborne geophysical coverage area, uranium mineralisations at Talmesi, Meskani, Kelardasht and the salt plugs of south Iran are also worthy of mention.

Mine development

At the Saghand uranium mine (1 and 2), feasibility studies and basic engineering designs (1994-1995) and mining preparation reports (1996) led to the construction of administration and industrial buildings and procurement of equipment (1997-1998). Shafts No. 1 and No. 2 were sunk from 1999 to 2002 and the underground development of the Saghand mine began in 2003.

The Khoshumi area is composed of 47 anomalies that are mainly related to metamorphite-type uranium deposits. Orefield No. 6 of this area was considered for feasibility studies. Five anomalies in Narigan turned out to be ore fields of hydrothermal and metasomatite-type uranium deposits. Mineral deposit No. 3 in the Narigan area was a candidate for feasibility studies.

Recent and ongoing uranium exploration and mine development activities

Uranium exploration activities

Following the development of a comprehensive plan, exploration activities are being performed within favourable areas from reconnaissance to detailed phases. The reconnaissance and prospecting phases are being undertaken in the central, southern, eastern, south-eastern and north-western provinces of the country, and uranium mineralisation with positive indications has been found in various geological environments. Uranium exploration (prospecting and general exploration) is being conducted in different parts of the country for different types of deposits, such as granite-related, metasomatite, volcanogenic, intrusive and sedimentary types.

* Secretariat Report based on Red Book 2020 and 8 March 2021 correspondence from Iranian authorities updating production figures published in Red Book 2020.

Mine development activities

Mines No. 1 and 2 in the Saghand mining and industrial complex are being developed. In mine No. 1, open-pit methods are being used to access orebodies after overburden stripping. Ore at mine No. 2 is being extracted through underground methods. For this purpose, main and ventilation shafts have been sunk and adits are being drilled. Also, some stopes are being developed at different levels for ore production. The uranium ores extracted from mines No. 1 and No. 2 are transported to the uranium production centre after being mixed.

Feasibility studies of other uranium ore deposits such as Narigan and Khoshoumi have been planned. The conceptual design of the Narigan deposit and the detailed design of the Khoshumi deposit have been completed.

Identified conventional resources (reasonably assured and inferred resources)

Based on exploration activities completed during 2017 and 2018, and considering overall changes since the last report, the total in situ RAR are 4 316 tU. These resources are related to metasomatic, granite-related and metamorphite deposit types.

Changes in inferred resources have occurred as a result of new discoveries, most of which are metasomatic-type mineralisation. Some of the inferred resources were moved to the RAR category because of additional studies. Total in situ inferred resources as of 1 January 2019 were 5 535 tU.

Undiscovered conventional resources (prognosticated and speculative resources)

Prognosticated resources amounted to 9 800 tU in the <USD 130/kgU cost category, whereas speculative resources were 48 100 tU in the unassigned cost category as of 2019. Ongoing exploration is focused on the following areas:

Kerman-Sistan metallogenic trend

The uranium mineralisation potential in this trend is associated with volcanic-related, metasomatic, granite-related and sedimentary types. Exploration is being conducted in several areas and considering the potential of these areas, some of them are expected to be selected for further exploration.

Naiin-Jandagh metallogenic trend

The uranium mineralisation potential occurs in granite-related, volcanic-related and polymetallic types. Surface studies are being undertaken in favourable areas and if results are positive, subsurface exploration will be performed.

Birjand-Kashmar metallogenic trend

The uranium mineralisation potential is associated with sedimentary, granite-related and volcanic-related types. Surface studies are being conducted in favourable areas, and if favourable results are obtained, further exploration, including borehole drilling and logging, will be undertaken.

Hamedan-Marand metallogenic trend

The uranium mineralisation potential is associated with granite-related, volcanogenic, intrusive and sedimentary types. Surface exploration has identified favourable areas for further subsurface exploration.

Unconventional resources

Recent studies have identified favourable areas for investigation of potential unconventional resources. This includes phosphate rocks, non-ferrous ores, ferrous ores, carbonatite and black shales. The evaluation of the potential of these resources is being carried out through a staged approach that includes conceptual designs for mining, extraction and processing. Speculative unconventional resources in the unassigned cost category are estimated at 53 000 tU.

Uranium production

Historical review

Uranium ore recovered by open-pit mining of the Gachin salt plug (surficial type) has been processed at the Bandar Abbas uranium plant since 2006.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #2
Name of production centre	Gachin	Ardakan
Production centre classification	Closed down in 2016	Existing
Date of first production	2006	2017
Source of ore:		
Deposit name(s)	Gachin	Saghand
Deposit type(s)	Salt Plug (Surfical)	Metasomatic
Recoverable resources (tU)	84.1	500
Grade (% U)	0.068	0.0552
Mining operation:		
Type (OP/UG/ISL)	OP	OP/UG
Size (tonnes ore/day)	70	400
Average mining recovery (%)	80	90
Processing plant:		
Acid/alkaline	Acid	Acid
Type (IX/SX)	SX	IX/SX
Size (tonnes ore/day)	70	280
Average process recovery (%)	73	80
Nominal production capacity (tU/year)	21	50
Plans for expansion		Yes
Other remarks		

Status of production facilities, production capability, recent and ongoing activities and other issues

The Bandar Abbas uranium plant began operating in 2006 with a nominal annual production capacity of 21 tU and closed down in 2016. A second production facility, located near Ardakan, began operating in 2017. It has a nominal annual production capacity of 50 tU and will be supplied with ore from the Saghand uranium mine.

Ownership structure of the uranium industry

The owner of the uranium industry is the Government of Iran and the operator is the Atomic Energy Organization of Iran (AEOI).

Future production centres

In addition to the currently operating Ardakan uranium plant production centre, feasibility studies for the planning of the Narigan production centre are underway.

Uranium exploration and development expenditures and drilling effort – domestic

(In IRR millions [Iranian Rial])

	2018	2019*	2020	2021 (expected)
Government exploration expenditures	208 500	174 000	NA	NA
Government development expenditures	365 750	617 700	NA	NA
Total expenditures	574 250	791 700	NA	NA
Government exploration drilling (m)	1 883	4 757	NA	NA
Government exploration holes drilled	11	48	NA	NA
Government exploration trenches (m)	2 670	1 509	NA	NA
Government exploration trenches (no.)	67	53	NA	NA
Government development drilling (m)	8 252	4 326	NA	NA
Government development holes drilled	1 650	721	NA	NA
Total drilling (m)	10 135	9 083	NA	NA
Total number of holes drilled	1 661	769	NA	NA

* Estimated according to Red Book 2020 projection.

Reasonably assured conventional resources by production method

(in situ tonnes U*)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	491	491	80-90
Open-pit mining (OP)	0	0	136	136	40-50
Unspecified	0	0	3 689	3 689	NA
Total	0	0	4 316	4 316	

* In situ resources.

Reasonably assured conventional resources by processing method

(in situ tonnes U*)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	491	491	80-90
Heap leaching** from OP	0	0	136	136	40-50
Unspecified	0	0	3 689	3 689	NA
Total	0	0	4 316	4 316	

* In situ resources. ** A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(in situ tonnes U*)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	653	653
Metamorphite	0	0	136	136
Metasomatic	0	0	3 527	3 527
Total	0	0	4 316	4 316

* In situ resources.

Inferred conventional resources by production method

(in situ tonnes U*)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	876	876	80-90
Unspecified	0	0	4 659	4 659	NA
Total	0	0	5 535	5 535	

* In situ resources.

Inferred conventional resources by processing method

(in situ tonnes U*)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	876	876	80-90
Unspecified	0	0	4 659	4 659	NA
Total	0	0	5 535	5 535	

* In situ resources.

Inferred conventional resources by deposit type

(in situ tonnes U*)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	479	479
Metamorphite	0	0	25	25
Volcanic-related	0	0	128	128
Metasomatic	0	0	4 903	4 903
Total	0	0	5 535	5 535

* In situ resources.

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	9 800	9 800

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	48 100

Historical uranium production by production method

(tonnes U in concentrate)

Production method	Total through end of 2018	2019**	2020**	Total through end of 2020**	2021 (expected)**
Open-pit mining*	90.7	4.2	4.2	99.1	4.2
Underground mining*	26.6	16.8	16.8	60.2	16.8
Total	117.3	21.0	21.0	159.3	21.0

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

** Estimate, based on Red Book 2020.

Historical uranium production by processing method

(tonnes U in concentrate)

Processing method	Total through end of 2018	2019*	2020*	Total through end of 2020*	2021 (expected)*
Conventional	117.3	21.0	21.0	159.3	21.0
Total	117.3	21.0	21.0	159.3	21.0

* Estimate, based on Red Book 2020.

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2018	2019*	2020*	Total through end of 2020*	2021 (expected)*
Metasomatic	33.2	21.0	21.0	75.2	21.0
Surficial	84.1	0.0	0.0	84.1	0.0
Total	117.3	21.0	21.0	159.3	21.0

* Estimate, based on Red Book 2020.

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)*	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)*	(%)
21.0	100	0	0	0	0	0	0	21.0	100

* Estimate, based on Red Book 2020.

Uranium industry employment at existing production centres

(person-years)

	2018	2019*	2020*	2021 (expected)*
Total employment related to existing production centres	280	280	280	280
Employment directly related to uranium production	95	95	95	95

* Estimate, based on Red Book 2020.

Mid-term production projection

(tonnes U/year)

2021*	2022	2025	2030	2035	2040
21.0	NA	NA	NA	NA	NA

* Estimate, based on Red Book 2020.

Mid-term production capability

(tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA

Net nuclear electricity generation

	2019	2020
Nuclear electricity generated (TWh net)	6.30*	6.30*

* Estimate, based on normal operation of Bushehr-1 reactor unit.

Installed nuclear generating capacity to 2040

(MWe gross capacity)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
915	915	1 889	1 889	2 863	5 075	6 975	7 925	6 975	7 925

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
160	160	320	325	490	910	1 230	1 390	1 230	1 390

Japan

Uranium exploration and mine development

Historical review

Domestic uranium exploration has been carried out by the Power Reactor and Nuclear Fuel Development Corporation (PNC) and its predecessor since 1956. About 6 600 tU of uranium resources were discovered in Japan before domestic uranium exploration activities were terminated in 1988. Overseas uranium exploration began in 1966 with activities carried out mainly in Australia and Canada, as well as other countries such as Niger, the People's Republic of China, the United States and Zimbabwe.

In October 1998, the PNC was reorganised into the Japan Nuclear Cycle Development Institute (JNC). The Atomic Energy Commission decided in February 1998 to terminate uranium exploration activities in 2000 and the JNC's mining interests and technologies were transferred to the private sector. In October 2005, the Japan Atomic Energy Agency (JAEA) was established by integrating the Japan Atomic Energy Research Institute and the JNC.

In April 2007, the Japanese government decided to resume overseas uranium exploration activities with financial support from Japanese companies through the Japan Oil, Gas and Metals National Corporation (JOGMEC). JOGMEC is carrying out exploration activities in Australia, Canada, Namibia, Uzbekistan and other countries.

Recent and ongoing uranium exploration and mine development activities

Japan-Canada Uranium Co. Ltd (JCU), which took over the JNC's Canadian mining interests, is continuing exploration activities in Canada while JOGMEC continues exploration activities in Uzbekistan and Namibia. Japanese private companies hold shares in companies developing uranium mines and also in those operating mines in Australia, Canada, Kazakhstan and Niger.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

About 6 600 tU of reasonably assured resources (recoverable) at <USD 130/kgU have been identified in Japan.

Uranium production

Historical review

The PNC established a test pilot plant with a capacity of 50 t ore/day at the Ningyo-toge mine in 1969. Its operation ended in 1982 with total production amounting to 84 tU. In 1978, a leaching test consisting of three 500 t ore vats with a maximum capacity of 12 000 t ore/year was initiated to process Ningyo-toge ore on a small scale. The vat leaching test was terminated at the end of 1987.

Secondary sources of uranium

Production of mixed oxide fuels

Production facilities

The JAEA plutonium fuel plant consists of three facilities, the Plutonium Fuel Development Facility (PFDF), the Plutonium Fuel Fabrication Facility (PFFF), and the Plutonium Fuel Production Facility (PFPF).

The PFDF, constructed for basic research and the fabrication of test fuels, started operating in 1966. As of 1 January 2021, approximately 2 tonnes of MOX fuel had been fabricated in the PFDF. The PFFF had two MOX fuel fabrication lines, one for the experimental fast breeder reactor Jōyō (FBR line) with a capability of 1 tonne MOX/yr and the second for the prototype advanced thermal reactor Fugen (ATR line) with 10 tonnes MOX/yr fabrication capability. The FBR line started operations in 1973, producing the initial fuel load for the experimental Jōyō sodium-cooled fast reactor. FBR line fuel fabrication ended in 1988 and Jōyō fuel fabrication was switched to the PFPF. The ATR line started operations in 1972 with MOX fuel fabrication for the Deuterium Critical Assembly in JAEA's O-arai Research and Development Center. Fuel fabrication for ATR Fugen was started in 1975 and ended in 2001. MOX fuel fabrication in both lines amounted to a total of approximately 155 tonnes.

The PFPF FBR line, constructed to supply MOX fuels for the prototype Monju FBR and the experimental Jōyō FR, has a production capability of 5 tonnes MOX/yr. The PFPF FBR line began operating in 1988 fabricating Jōyō fuel reloads. Fuel fabrication for the FBR Monju was started in 1989. As of 1 January 2021, approximately 16 tonnes of MOX fuels had been fabricated in the PFPF.

Use of mixed oxide fuels

Monju prototype fast breeder reactor

Monju achieved initial criticality in April 1994 and began supplying electricity to the grid in August 1995. However, during a 40% power operation test of the plant, a sodium leak accident in the secondary heat transport system in December 1995 interrupted operation. After carrying out an investigation to determine the cause, a two-year comprehensive safety review, and the required licensing procedure, the permit for plant modification (including countermeasures to reduce the likelihood of sodium leak accidents) was issued in December 2002 by the Ministry of Energy, Trade and Industry. The JAEA completed a series of countermeasure modifications in May 2007, implemented a modified system function test until August 2007, and then conducted an entire system function test. The existing 78 slightly used and 6 newly fabricated fuel assemblies were loaded by 27 July 2009. Following the system start-up test, Monju was restarted on 6 May 2010. The core confirmation test was completed on 22 July 2010 and 33 freshly fabricated fuel assemblies were loaded by 18 August 2010. However, after refuelling, the in-vessel fuel transfer machine was dropped on 26 August 2010 and removed by 24 June 2011.

The government formally decided on 21 December 2016 to decommission the Monju FBR in Fukui Prefecture. It plans to remove the spent nuclear fuel by 2022 and finish dismantling the facility by 2047.

Experimental fast reactor Jōyō

The experimental fast reactor Jōyō attained criticality in April 1977 with the MK-I breeder core. As an irradiation test bed, the Jōyō MK-II core achieved maximum design output of 100 MW in March 1983. Thirty-five duty cycle operations and thirteen special tests with the MK-II core had been completed by June 2000. The MK-III high-performance irradiation core, with design output increased to 140 MW, achieved initial criticality in July 2003. Six duty cycle operations and four special tests with MK-III core were completed. The Jōyō net operation time reached around 70 000 hours and 588 fuel subassemblies were irradiated during MK-I, MK-II and MK-III core operations.

The new regulatory requirements for research reactors were launched on 18 December 2013. The JAEA submitted an application to comply with the new regulatory requirements for research reactors to Jōyō with MK-IV core (100 MW) on 30 March 2017. A safety review is being conducted.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Japan has relatively scarce domestic uranium resources and therefore relies on overseas uranium supply. A stable supply of uranium resources is to be ensured through long-term purchase contracts with overseas uranium suppliers, direct participation in mining development, and diversification of suppliers and countries.

Since the severe accident at the Fukushima Daiichi Nuclear Power Plant in March 2011, all operational reactors in Japan that normally provide about 30% of electricity production have been progressively taken out of service during scheduled refuelling and maintenance outages. As of 1 January 2021, nine reactors are in operation: Kansai Electric Power Company's Ooi Nuclear Power Plant units 3 and 4; Takahama Nuclear Power Plant units 3 and 4; Kyushu Electric Power Company's Genkai Nuclear Power Plant units 3 and 4; Sendai Nuclear Power Plant units 1; Shikoku Electric Power Company's Ikata Nuclear Power Plant unit 3; and Kansai Mihama Nuclear Power Plant unit 3.

Uranium exploration and development expenditures – non-domestic

(JPY million [Japanese yen])

	2018	2019	2020	2021 (expected)
Private* exploration expenditures	N/A	N/A	N/A	N/A
Government exploration expenditures	247	348	347	297
Private* development expenditures	N/A	N/A	N/A	N/A
Government development expenditures	N/A	N/A	N/A	N/A
Total expenditures	247	348	347	297

* Expenditures made by private companies. Government expenditures refer to those related to majority government funding.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining	0	0	6 600	6 600	85
Total	0	0	6 600	6 600	85

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG			6 600	6 600	85
Total			6 600	6 600	85

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone			6 600	6 600
Total			6 600	6 600

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining[1]	39	0	0	39	0
Underground mining[1]	45	0	0	45	0
Total	84	0	0	84	0

1. Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	45	0	0	45	0
Heap leaching*	39	0	0	39	0
Total	84	0	0	84	0

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	84	0	0	84	0
Total	84	0	0	84	0

Mixed oxide fuel production and use

(tonnes natural U-equivalent)

Mixed oxide (MOX) fuel	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Production	684	0	0	684	N/A
Use	1 154	16	0	1 170	N/A
Number of commercial reactors using MOX	1	1	0	0	N/A

Reprocessed uranium use

(tonnes natural U-equivalent)

Reprocessed uranium	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Production	645	N/A	N/A	N/A	N/A
Use	217	N/A	N/A	N/A	N/A

Net nuclear electricity generation (TWh net)

	2019	2020
Nuclear electricity generated (TWh net)	65.6 TWh	42.9 TWh

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
31 679	31 679	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Jordan

Uranium exploration and mine development

Historical review

Uranium exploration in Jordan started in the 1980s with work by the Natural Resource Authority (NRA). The work included an airborne gamma-spectrometric survey covering the entire Hashemite Kingdom of Jordan, and ground radiometric surveys over selected sites and exploration trenches.

During the 1990s, reconnaissance and exploration studies revealed surficial uranium deposits distributed in several areas of the country:

- Central Jordan: 1 700 trenches and over 2 000 samples from exploration were analysed for uranium using a fluorometer, which revealed the occurrence of uranium mineralisation as minute mineral grains disseminated within fine calcareous Pleistocene sediments and as yellowish films of carnotite and other uranium minerals coating fractures of fragmented chalk or marl of Mastrichtian-Paleocene age. Results of channel sampling in three areas indicated uranium contents ranging from 120 to 1 870 ppm U (0.012% to 0.187% U) over an average thickness of about 1.3 m, with overburden of about 0.5 m.
- The airborne gamma-spectrometric survey identified several other areas with radiation anomalies (Mafraq, Ruwayshid, Russeifa, Hasa-Qatrana, Dana, Wadi Al-Bahiyyah, Dubaydib, Al Awja, and WadiSahabAlabyad) and potential for hosting uranium mineralisation. However, only three areas were covered by follow-up reconnaissance studies (Mafraq, Wadi Al-Bahiyyah and WadiSahabAlabyad).

In 2008, the Jordan Atomic Energy Commission (JAEC) was established, in accordance with the Nuclear Energy Law (Law No. 42) of 2007 and amendments in 2008. The JAEC is the official entity entrusted with the development and implementation of the Jordanian nuclear power programme. The exploration, extraction, and mining of all nuclear materials, including uranium, thorium, zirconium, and vanadium, are under the authority of the JAEC.

The Nuclear Fuel Cycle Commission of JAEC is in charge of developing and managing all aspects of the nuclear fuel cycle, including uranium exploration, extraction, production, securing fuel supply and services, nuclear fuel management and radioactive waste management. The JAEC uranium policy is to maximise sovereignty while creating value from resources and to avoid concessions to foreign companies. To attract investors and operate on a commercial basis, the JAEC created Jordan Energy Resources Inc. as its commercial arm.

In September 2008, the JAEC signed an exploration agreement with Areva S.A. (now Orano S.A.) and created the Jordanian French Uranium Mining Company (JFUMC), a joint venture created to carry out all exploration activities and which led to a feasibility study on developing resources in the Central Jordan Area. In January 2009, the JAEC signed a memorandum of understanding entitling Rio Tinto to carry out reconnaissance and prospecting in three areas (north of Al-Bahiyyah, Wadi SahbAlabiadh and Rewashid). Exploration activities by Jordanian teams in co-operation with the China Nuclear International Uranium Corporation were carried out in two other areas (Mafraq and Wadi Al-Bahiyyah).

During 2009-2012, the JFUMC explored the northern part of the central Jordan licence area, which included geological mapping, a radiometric survey, trenching, sampling, chemical analyses, development of an environmental impact assessment and a hydrogeological study, building a database inventory, and drilling a total of 5 691 boreholes that were surveyed for gamma radiation at 0.10 m intervals. These data have been integrated to intervals of 0.50 m, which is equal to the length of the drill core samples that were assayed by Inductively Coupled Plasma (ICP) and X-Ray Fluorescence (XRF) methods and used for calibration of the equivalent uranium (eU) data. Jordan terminated the mining agreement with the JFUMC at the end of 2012.

In 2013, the JAEC established the Jordan Uranium Mining Company (JUMCO) as a commercial arm to complete the exploration and resource estimation of the Central Jordan Uranium Deposits.

Recent and ongoing uranium exploration and mine development activities

During 2013-2018, JUMCO completed several exploration activities, including trenching, channel sampling (QA/QC) and chemical analyses. In June 2018, the third JORC compliant report was issued.

The estimated resources for the Central Jordan Uranium Project (CJUP) deposit are reported in compliance with JORC (2012) as mineral resources at an 80 ppm U (0.008% U) cut-off grade, and include measured, indicated and inferred categories. In total, the CJUP deposit contains approximately 303 Mt of uranium mineral ore at an average grade of 116 ppm U_3O_8 (0.01% U), as of February 2018.

Plans for 2019-2020 included a drilling programme on a 50 x 50 m grid in selected areas to upgrade the resource category of the deep mineralised layer to measured resources leading to pre-feasibility studies. During the second half of 2019, JUMCO completed the development of the required wireline logging capacity required to execute the planned drilling campaign. But upon final preparation during the first quarter of 2020, the COVID-19 pandemic stopped all exploration activities and caused the plan to be put on hold.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Central Jordan Area

JORC compliant resource estimations include 33 300 tU as inferred resources and 8 000 tU as reasonably assured resources (in situ).

Hasa-Qatrana Area

In 2012, a preliminary resource estimation was carried out in this area, covering seven mineralised zones with total in situ inferred resources of about 28 700 tU.

Undiscovered conventional resources (prognosticated and speculative resources)

No change (about 50 000 tU as speculative resources in carbonate rock deposits in Mafraq and Wadi Al-Bahiyyah areas and sandstone deposits in Dubaydib Area).

Unconventional resources and other materials

No change (about 100 000 tU in the phosphate deposits).

Uranium production

Historical review

Jordan does not currently produce uranium. In 1982, a feasibility study for uranium extraction from phosphoric acid was completed by an engineering company (Lurgi A.G. of Frankfurt, Germany) on behalf of the Jordan Fertiliser Industry Company, and the company was subsequently purchased by the Jordan Phosphate Mines Company. One of the extraction processes evaluated was originally found to be economically feasible, but as uranium prices dropped in the 1990s, the process became uneconomic and construction of an extraction plant was deferred.

In 2009, SNC-Lavalin performed a technological and economic feasibility study for the recovery of uranium from the phosphoric acid produced at the Aqaba Fertilizer Complex. This study was performed jointly with Prayon Technologies S.A. The profitability was evaluated to be 6.8% for the internal rate of return.

JUMCO is currently conducting research to develop optimised extraction parameters, including:

- Research on dynamic alkaline leaching of central Jordan ore, which has provided promising results of more than 90% recovery.
- The evaluation of process parameters and recovery of uranium at a laboratory scale, using 1-2 m high, 0.14 m diameter extraction columns. The results were promising with more than 80% recovery.
- The evaluation of the scale-up parameters and extraction process at a small-scale pilot-plant, using extraction columns, 6 m high and 0.5 m in diameter, for a large-scale heap leach. Recovery was in line with previous laboratory studies.
- Installation and commissioning of a pilot-scale uranium extraction plant (three cribs, 3 x 3 x 6 m) with a capacity of approximately 180 tonnes of ore that was commissioned for uranium extraction in 2021. The purpose of such a pilot-scale plant is to fine-tune the developed process for extracting uranium from the local ores of Central Jordan and to generate the technical data needed for finalising the detailed engineering of the commercial plant as well as feeding the bankable feasibility study.
- Mutual collaboration between Jordan and the International Atomic Energy Agency has enabled JUMCO to establish an on-site analytical laboratory to support the exploration and extraction activities; the laboratory was commissioned in 2020.
- Planning to build one cell heap leaching pad. This includes finalising engineering drawings, manufacturing units needed, supporting infrastructure, etc.

Status of production capability

Jordan does not have firm plans to produce uranium. Nevertheless, JUMCO is investigating the perspectives of uranium production in the country and will prepare a bankable feasibility study as soon as other related studies are finished.

Uranium requirements

In 2010, Jordan announced plans to develop civil nuclear power, stating its intention to have four units in operation by 2040. Nuclear co-operation agreements have been signed with a number of countries, including Canada, China, France, Japan, Korea, Russia and the United Kingdom. In 2011, it was reported that Jordan would be receiving bids from nuclear power plant vendors. Currently, the kingdom imports over 95% of its energy needs, and disruptions in natural gas supply from Egypt have reportedly cost Jordanians more than USD 1 million a day.

Despite the need to generate electricity by other means, the accident at the Fukushima Daiichi nuclear power plant created some local resistance to the plan to have one 700-1 200 MWe reactor operating by 2020 and a second unit of similar size by 2025. This has created some issues related to site selection for the planned reactor construction.

Applying exclusion and discretionary criteria, a country-wide survey was carried out and a proposed site (2.5 km^2) was selected for the construction of the nuclear power plant. Currently, detailed studies are being carried out to evaluate and characterise the selected site, as well as other studies related to the construction and operation of the nuclear power plant.

National policies related to uranium

With Jordan's intention to develop a peaceful atomic energy programme to generate electricity and water desalination, the JAEC restarted uranium exploration in the country with the goal of achieving some energy self-sufficiency.

Uranium exploration and development expenditures and drilling effort – domestic

(JOD [Jordanian dinars])

	2018	2019	2020	2021 (expected)
Government exploration expenditures	3 420 000	2 500 000	1 730 000	2 000 000
Total expenditures	3 420 000	2 500 000	1 730 000	2 000 000
Government exploration trenches (m)	6 944	0	0	0
Government trenches	1 736	0	0	0

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	8 000	8 000	NA
Total	0	0	8 000	8 000	

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Heap leaching* from OP	0	0	8 000	8 000	NA
Total	0	0	8 000	8 000	

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Surficial	0	0	8 000	8 000
Total	0	0	8 000	8 000

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	62 000	62 000	NA
Total	0	0	62 000	62 000	

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Heap leaching* from OP	0	0	33 300	33 300	NA
Unspecified	0	0	28 700	28 700	NA
Total	0	0	62 000	62 000	

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Surficial	0	0	62 000	62 000
Total	0	0	62 000	62 000

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	50 000	NA

Kazakhstan

Uranium exploration

Historical review

Since uranium exploration began in Kazakhstan in 1944, about 60 uranium deposits have been identified in six uranium ore provinces – Shu-Sarysu, Syrdarya, Northern Kazakhstan, Caspian, Balkhash and Ili.

By the late 1970s, unique deposits suitable for uranium mining by in situ leaching (ISL), such as Inkai, Mynkuduk, Moinkum, Kanzhugan and North and South Karamurun, were discovered.

Recent and ongoing uranium exploration and mine development activities

During 2019 and 2020, exploration was undertaken at Inkai, Budenovskoye in the Shu-Sarysu Uranium Province and at the Northern Kharasan and Zarechnoye deposits in the Syrdaria Uranium Province.

JV Katco LLP continued pilot production in the southern part of site No. 2 (Tortkuduk) of the Moinkum deposit. In 2017 exploration was completed and a technical report on resource estimates was approved.

Inkai JV LLP returned sites No. 2 and 3 to the state in 2017 and in 2019-2020 continued further exploration of site No. 1 of the Inkai field.

The JV Khorasan-U LLP and the Baiken-U LLP completed exploration at the Northern Kharasan field.

In 2021, the Zarechnoye JSC completed additional exploration and re-evaluation of resources at the Zarechnoye deposit.

Exploration at the Zhalpak field with pilot production began in 2017 and the work was completed in 2020.

As a result of exploration in 2019-2020, an increase in C2 (inferred) resources by 55 409 tonnes of uranium was obtained at sites No. 6 and No. 7 of the Budenovskoye field.

In 2020 Volkovgeology JSC completed a state geological study contracted by NAC Kazatomprom JSC. The study focused on the potential for new “sandstone” type deposit discoveries (suitable for mining by in situ leaching) in the perspective areas of the Shu-Sarysu uranium province.

No uranium exploration and development was performed by Kazakh enterprises outside of Kazakhstan.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2021, identified in situ uranium resources available at a cost < USD 260/kgU amounted to 990 954 tU, including 822 334 tU of resources amenable for ISL recovery. Total recoverable resources, with mining and processing losses taken into consideration, amounted to 874 704 tU, including 731 877 tU amenable for ISL mining.

Total identified in situ resources decreased by 111 725 tU compared to the previous report as a result mainly of mining depletion by 45 508 tU (including production and mining losses) during 2019-2020, as well as the transfer of 121 630 tU of the Kosachinoye field resources (open pit and underground) to the subeconomic category. Inferred resources at sites No. 6 and No. 7 of the Budenovskoye field (JV Budennovskoye) increased by 55 409 tU.

In Kazakhstan, 95% of all identified in situ uranium recoverable resources available at <USD 40/kgU, 93% of those at <USD 80/kgU, 83% at <USD 130/kgU and 77% at <USD 260/kgU are associated with existing and committed production centres.

Undiscovered conventional resources (prognosticated and speculative resources)

A re-evaluation of prognosticated (P1 in national classification) and speculative (P2+P3) resources was carried out during the reporting period 2019 to 2020. Of the 114 696 tU of prognosticated resources, 113 166 tU are related to sandstone-type deposits and 1 530 tU to metasomatite type.

Of the 219 380 tonnes of speculative resources, 85% relate to the sandstone-type and 15% relate to unconformity or metasomatite-type mineralisation.

Unconventional resources and other materials

Estimates are not made of Kazakhstan's unconventional uranium resources and other materials.

Uranium production

Historical review

The growth of uranium production in Kazakhstan is connected with the development of sandstone-type uranium deposits, suitable for ISL mining, which is one of the lowest cost methods of uranium production that has a minimal impact on the environment when done properly.

Production capability and recent and ongoing activities

Over the two-year reporting period (2019 to 2020), uranium production in Kazakhstan totalled 42 285 tU. As of 1 January 2021, the total capacity of uranium production centres in Kazakhstan was 27 000 tU/yr. Uranium was mined at the Kanzhugan, Moinkum, Akdala, Uvanas, Mynkuduk, Inkai, Budenovskoye, North and South Karamurun, Irkol, Zarechnoye, Semizbay and Northern Kharasan deposits. All uranium was mined by ISL method.

All ISL mines in Kazakhstan use sulphuric acid to recover uranium in pregnant solutions. Further processing of pregnant solutions includes sorption on ion-exchange resins followed by elution technologies and uranyl salts precipitation from eluates, with further extraction of refined U_3O_8 concentrates. Five mining enterprises (the Appak LLP, Karatau LLP, JV South Mining Chemical Company LLP, Inkai LLP, and Baiken-U LLP) produce uranium concentrates through the precipitation of uranium using hydrogen peroxide and further calcination without an extraction stage.

Shu-Sarysu uranium province

Development of the Uvanas, Eastern Mynkuduk, Kanzhugan and Moinkum deposits (the southern part of site No. 1 and site No. 3) is carried out by Kazatomprom-Sauran LLP. The subsoil use contract for the Moinkum deposit Central section was transferred from Kazakhstan's national atomic company, Kazatomprom JSC, to Kazatomprom-Sauran LLP in 2021.

Development of the Mynkuduk deposit, Central section, is carried out by Ortalyk LLP.

JV Katco LLP operates the Moinkum deposit (northern part of sites No. 1 [Southern] and site No. 2 [Tortkuduk]).

JV Inkai LLP operates the Inkai deposit (site No. 1) and sites No. 2 and No. 3 were returned to the state fund. In 2018, NAC Kazatomprom JSC obtained exploration contracts for areas No. 2 and No. 3 of the Inkai deposit.

Appak LLP develops the Western site of the Mynkuduk deposit.

JV Akbastau JSC operates sites No. 1, No. 3 and No. 4 of the the Budenovskoye deposit. Karatau LLP develops site No. 2 of the Budenovskoye deposit, and processes solutions extracted by JV Akbastau from the sites No. 1 and No. 3 of the Budenovskoye deposit.

JV South Mining Chemical Company LLP (SMCC) operates the Akdala and Inkai (site No. 4) deposits.

Syrdarya uranium province

NAC Kazatomprom JSC, through the Mining Group-6 LLP, operated the North and South Karamurun deposits.

The Irkol deposit was developed by Semizbay-U LLP.

Baiken-U LLP carries out uranium production at the Northern Kharasan (site Kharasan-2) deposit.

Khorasan-U LLP operates the Northern Kharasan (site Kharasan-1) deposit, and processing is carried out by Kyzylkum LLP.

JV Zarechnoye JSC develops the Zarechnoye deposit.

The company Balausa LLP is developing, by open-pit mining, the Bala-Sauskandykskoye deposit where uranium is a by-product to vanadium. A very small amount of uranium-bearing ore, containing about 4 005 kgU, was mined and stockpiled during 2019-2020.

Northern Kazakhstan uranium province

Stepnogorsk Mining Chemical Complex LLP has stopped underground mining at the Vostok and Zvezdnoe deposits and the mine was closed in 2013.

The Semizbay deposit is being developed by Semizbay-U LLP.

Ownership structure of the uranium industry

In 2020, the state share of uranium production in Kazakhstan was 55% (10 736 tU), including 36% from NAC Kazatomprom owing to its partnership in joint ventures and 19% by NAC Kazatomprom's own production. In 2020, the production share of private foreign companies in Kazakhstan was 13.7%, while the share of state foreign companies in Kazakhstan was 31% of total production. NAC Kazatomprom is majority owned (75%) by a state-owned company, the Samruk-Kazyna JSC national wealth fund, and 25% of its shares are traded on the London Stock Exchange.

NAC Kazatomprom JSC owns 100% of the following production centres: Kazatomprom-Sauran LLP, Mining Group-6 LLP, and Ortalyk LLP, all of which produce uranium by ISL.

In 2020, NAC Kazatomprom held shares in joint ventures with private companies from Canada, Japan, Kyrgyzstan and Kazakhstan (JV Inkai LLP, Appak LLP, Kyzylkum LLP, Khorasan-U LLP, Baiken-U LLP, JV Zarechnoe JSC, JV Budenovskoye LLP), and with foreign state companies from China, Russia and France (Semizbay-U LLP, JV Katco LLP, SMCC LLP, JV Akbastau JSC, Karatau LLP, JV Zarechnoe JSC, Kyzylkum LLP, Khorasan-U LLP).

Balausa LLP has 100% foreign participation.

Employment in the uranium industry

In 2020, the number of employees working in the NAC Kazatomprom uranium industry amounted to 21 186, of which 7 060 are directly related to uranium production and the remainder are involved in general-purpose auxiliary and service facilities.

One of the important areas of personnel policy of NAC Kazatomprom JSC and its subsidiaries and affiliates (hereinafter referred to as subsidiaries) is the development and training of personnel.

Within the framework of personnel training in specialties relevant to the nuclear industry, the company and its subsidiaries co-operate with leading universities and colleges of the Republic of Kazakhstan and abroad. To date, this encompasses 32 universities in specialised areas, including Nazarbayev University, KazNT University (named after K.I. Satpayev), ENU (named after L.N. Gumilev), KIMEP University, MEPhI, TPU, and others. Training in working professions is carried out in the following colleges: Semey Geological Exploration College, M. Auezov South State University College, Taraz Humanitarian and Technical College, Ust-Kamenogorsk Multidisciplinary Technological College, as well as the Eastern Technical and Humanitarian College, College No. 24 (Taukent, Turkestan region), and the Shieli Industrial and Agrarian College.

NAC Kazatomprom JSC continues co-operation with KazNITU named after K.I. Satpayev (Satpayev University), the basis for the creation of the first International Scientific and Educational Center of the Nuclear Industry (ISECNI) in the country, within which employees of the company and subsidiaries, as well as individuals, are trained at the expense of subsoil users in priority specialties for the nuclear industry. Also, the company is working together with EKSTU after D. Serikbayeva developed a master's degree programme in the specialties “Nuclear Energy Materials” and “Innovative Technologies for Producing Uranium Products”, as well as new activities covering fuel assembly production and refining production, and created an international department, “New Materials for the Nuclear Industry”, which includes leading scientists and specialists from St. Petersburg Polytechnic University and Tomsk Polytechnic University of the Russian Federation.

In 2020, as part of the replication of the “Zhas-Orken” programme initiated by JSC Samruk-Kazyna, NAC Kazatomprom JSC launched “Izbasar”, its local programme for the development of young specialists. The purpose of the programme is to nurture talented leaders with the prospect of career growth in the enterprises of NAC Kazatomprom JSC. The programme provides a unique experience of internships in several enterprises of the company, along with special training.

For the preservation and transfer of knowledge in NAC Kazatomprom JSC, the School of Internal Trainers was launched, with select employees of the company and subsidiaries receiving certification to carry out coaching activities and share their knowledge and experience with colleagues.

Much attention is also paid to professional development programmes for employees, including compulsory training in accordance with the legislation of the Republic of Kazakhstan, and for the implementation of targeted training programmes (leadership development, efficient production, corporate culture, safety culture, etc.).

Since 2019, a corporate training centre, Kazakhstan Nuclear University, was formed at the Center for the Development of Professional Competencies (CDPC) of NAC Kazatomprom JSC. It aims to grow the professional competencies of engineers, technical workers and working personnel. Within the framework of the CDPC, professional development programmes for employees of NAC Kazatomprom JSC in mining enterprises were developed and implemented in 14 profile areas of activity.

In addition, NAC Kazatomprom JSC created centres for some subsidiaries and jointly controlled enterprises where employees are trained in occupational, industrial electrical and fire safety, technical basics and forerunners. Training is also provided in other positions, such that of slinger, crane operation or cradle worker, with certificates issued after successful completion of the training.

The fulfilment of the licence and contractual obligations of the company and its contracting enterprises is carried out following the Code of the Republic of Kazakhstan "On Subsoil and Subsoil Use", as well as the joint order of the Minister of Energy of the Republic of Kazakhstan dated 15 May 2018 (No. 185) and the Minister of Education and Science of the Republic of Kazakhstan dated 17 May 2018 (No. 211) "On approval of the Rules for financing the training of Kazakhstani personnel by subsoil users during the period of production of hydrocarbons and uranium."

According to the contract terms for subsurface use, the annual mandatory costs for training and retraining of personnel amounts to 1% of the annual costs of exploration and 1% of the annual operating costs during uranium mining.

Uranium production centre technical details

(as of 1 January 2021)

	Centre # 1	Centre # 2	Centre # 3	Centre # 4	Centre # 5	Centre # 6	Centre # 7	Centre # 8
Name of production centre	Kazatomprom-SaUran LLP		Mining Group-6 LLP	JV South Mining Chemical Company LLP	JV Katko LLP	JV Inkai LLP	JV Zarechnoe JSC	Karatau LLP
	Taukent Mining Chemical Plant	Stepnoye Mining Group						
Production centre classification	Existing	Existing	Existing	Existing	Existing	Existing	Existing	Existing
Date of first production	1982	1978	1985	2001	2004	2004	2007	2007
Source of ore:								
Deposit name(s)	Kanzhugan, Moinkum (sites 1, 3)	Mynkuduk (Eastern site), Uvanas	North & South Karamurun	Akdala, Inkai (site 4)	Moinkum (sites 1, 2), Tortkuduk	Inkai (site 1)	Zarechnoye,	Budenovskoe (site 2)
Deposit type(s)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Resources in situ (tU)	26 999	5 729	16 821	80 437	56 061	135 006	7 748	41 404
Grade (% U)	0.052	0.031	0.080	0.052	0.071	0.056	0.050	0.096
Mining operation:								
Type (OP/UG/ISL)	ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL
Size (tonnes ore/day)								
Average mining recovery (%)	87	90	91	90	85	85	90	90
Processing plant:								
Acid/alkaline	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid
Type (IX/SX)	IX	IX	IX	IX	IX	IX	IX	IX
Size (kilolitre/day)	85 000	60 000	60 000	140 000	100 000	80 000	80 000	60 000
Average process recovery (%)	98.9	98.7	98.7	98.9	98.9	98.9	98.5	98.9
Nominal production capacity (tU/year)	1 000	1 300	1 000	3 000	4 000	4 000	1 000	3 200
Plans for expansion (yes/no)	No	No	No	No	No	Yes	No	Yes

Uranium production centre technical details *(cont'd)*

(as of 1 January 2021)

	Centre # 9	Centre #10	Centre #11	Centre # 12	Centre # 13	Centre # 14	Centre # 15	Centre # 16
Name of production centre	Ortalyk LLP	Appak LLP	Khorasan-U LLP	Bayken-U LLP	JV Akbastau JSC	Semyzbai-U LLP	Ortalyk LLP	Budenovskoe LLP
Production centre classification	Existing	Existing	Existing	Existing	Existing	Existing	Committed	Prospective
Date of first production (year)	2007	2008	2008	2009	2009	2007	2016 pilot mining	2020 pilot mining
Source of ore:								
Deposit name(s)	Mynkuduk (Central site)	Mynkuduk (Western site)	North Kharasan (site 1)	North Kharasan (site 2)	Budennovskoe (sites 1, 3, 4)	Semyzbai, Irkol	Zhalpak	Budennovskoe (sites 6, 7)
Deposit type(s)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Resources in situ (tU)	24 637	17 195	38 342	18 423	39 682	32 112	14 320	88 074
Grade (% U)	0.047	0.027	0.204	0.117	0.089	0.050	0.033	0.072
Mining operation:								
Type (OP/UG/ISL)	ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL
Size (tonnes ore/day)								
Average mining recovery (%)	90	90	90	90	90	87	90	NA
Processing plant:								
Acid/alkaline	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid
Type (IX/SX)	IX	IX	IX	IX	IX	IX	IX	IX
Size (kilolitre/day)	70 000	60 000	50 000	60 000	20 000	85 000	0	0
Average process recovery (%)	98.5	98.9	98.5	98.5	98.9	98.6	NA	NA
Nominal production capacity (tU/year)	2 000	1 000	2 000	2 000	2 000	1 200	NA	NA
Plans for expansion (yes/no)	Yes	No	Yes	No	Yes	No	Yes	Yes

Future production centres

JV Budenovskoye LLP is engaged in exploration and production of blocks No. 6 and No. 7 of the Budenovskoye field. The subsoil use contract was transferred in 2017 from NAC Kazatomprom JSC. In October 2020, the JV obtained a contract for uranium mining at sites No. 6 and No. 7 of the Budenovskoye deposit with pilot production amounting to 321 tonnes.

After exploration was completed in September 2020, the contract for exploration of the Zhalpak deposit was transferred from NAC Kazatomprom JSC to Ortalyk LLP, prior to applying for a contract to mine the deposit.

Since 2019, exploration has been underway at sections #2 and #3 of the Inkai deposit.

Completion of prospecting and exploration in new promising areas of Shu-Sarysu and Syrdarya uranium-ore provinces has led to the possibility of creating new ISL mines.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

Mixed oxide (MOX) fuel is neither produced nor used in Kazakhstan.

Production and/or use of re-enriched tails

Uranium obtained through re-enrichment of depleted uranium tails is neither produced nor used in Kazakhstan.

Environmental activities and social cultural issues

Environmental activities

Subsoil users created a liquidation fund to eliminate the effects of operations on subsoil use in Kazakhstan. Contributions to the liquidation fund during the exploration and extraction of subsurface users are produced annually at a rate of at least 1% of the annual cost of exploration and production in a special deposit account in any bank in the state.

In 2019-2020, a project for the remediation of waste blocks at the Kanzhugan ISL field was initiated.

In the framework of environmental policy in Kazakhstan, a number of measures to improve environmental protection and encourage rational use of natural resources have been implemented in recent years. Each uranium venture in Kazakhstan has developed a short-term waste management plan, which includes measures to reduce the generation and accumulation of wastes. Reliable systems to monitor the environment and radiation safety at uranium mines and production sites have been put in place. The purpose of environmental monitoring across the operations of the company is to provide reliable information on the environmental impact of the enterprise and to implement possible changes in adverse or dangerous situations.

Environmental safety has a significant role in the effective functioning of the system of industrial environmental monitoring.

Social and/or cultural issues

All contracts for uranium exploration and mining provided by the government require financial contributions to local social and cultural improvements. All subsoil users are obliged to finance the establishment, development, maintenance and support of the regional social sphere, including health care facilities for employees and local citizens, education, sport, recreation and other activities in accordance with the Strategy of NAC Kazatomprom JSC and by an agreement with local authorities.

Contributions from each operator amount to:

- USD 30 000 to 100 000 per year (during the exploration period);
- up to 15% of annual operational expenses or USD 50 000 to 350 000 per year (during the mining period).

Expenditures on environmental activities and social cultural issues in 2019-2020

(KZT million)

	2019	2020	Total
Environmental impact assessments and monitoring	308	615	923
Tailings impoundment	143	146	289
Waste rock management	349	324	673
Effluent management	25	29	54
Site rehabilitation	265	4	269
Regulatory activities	108	76	184
Social and/or cultural issues	262	345	607

Uranium demand

Domestic demand for natural and enriched uranium is not expected in Kazakhstan over the next decade. Construction of a nuclear power plant is under consideration.

Supply and procurement strategy

At present, the entire volume of uranium produced in Kazakhstan is exported to the world market.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

In January 2017, due to the prolonged recovery of the uranium market, Kazatomprom reduced uranium production by approximately 10% for the year. In December 2017, given the challenging market conditions, and in light of continued oversupply in the uranium market, Kazatomprom announced further production cuts by 20% below the original Subsoil Use Contracts for 2018-2020. In August 2019, Kazatomprom announced its intention to continue to flex down production by 20%, compared to the planned levels under Subsoil Use Contracts through 2021. Likewise, in August 2020, Kazatomprom announced its intention to continue to cut production by 20% until 2022.

On 13 November 2018, Kazatomprom made its stock market debut after raising USD 450 million from investors in London and Astana. Kazatomprom sold 15% of its stock in the dual-listing offering, which valued the company at USD 3 billion. The portion of its shares in free float was eventually increased to 25% because of two secondary public offerings (SPOs) in September 2019 and June 2020.

Uranium exploration and development expenditures and drilling effort – domestic

(KZT million)

	2018	2019	2020	2021 (expected)
Industry* exploration expenditures	11 324	5 980	4 617	2 274
Government exploration expenditures	0	0	0	0
Industry* development expenditures	1 404	1 165	750	1 888
Government development expenditures	0	0	0	0
Total expenditures	12 728	7 145	5 367	4 162
Industry* exploration drilling (m)	712 250	362 136	433 462	205 015
Industry* exploration holes drilled	1 598	539	641	541
Industry exploration trenches (m)	0	0	0	0
Industry trenches (number)	0	0	0	0
Government exploration drilling (m)	0	0	0	0
Government exploration holes drilled	0	0	0	0
Government exploration trenches (m)	0	0	0	0
Government trenches (number)	0	0	0	0
Industry* development drilling (m)	217 718	230 647	358 957	505 522
Industry* development holes drilled	503	664	617	1 105
Government development drilling (m)	0	0	0	0
Government development holes drilled	0	0	0	0
Subtotal exploration drilling (m)	712 250	362 136	433 462	205 015
Subtotal exploration holes drilled	1 598	539	641	541
Subtotal development drilling (m)	217 718	230 637	358 957	505 522
Subtotal development holes drilled	503	664	617	1 105
Total drilling (m)	929 968	592 783	792 419	710 537
Total number of holes drilled	2 101	1 203	1 258	1 646

* Non-government

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	4 179	31 941	55 586	83
Open-pit mining (OP)	0	0	31 177	31 177	91
In situ leaching acid	283 142	351 557	351 557	351 557	89
Total	283 142	355 736	414 675	438 320	

The recovery factor for underground mining is 90%, for ore processing it is 92.5%.

The recovery factor for open-pit mining is 95%, for ore processing it is 96%.

The recovery factor during extraction by the ISL method is 90%, during the processing of ISL solutions it is 99%.

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	4 179	31 941	55 586	83
Conventional from OP	0	0	31 177	31 177	91
In situ leaching acid	283 142	351 557	351 557	351 557	89
Total	283 142	355 736	414 675	438 320	

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	283 142	351 557	351 557	351 557
Metasomatite	0	4 179	15 925	30 299
Phosphate deposits*	0	0	29 184	38 455
Lignite-coal*	0	0	18 009	18 009
Total	283 142	355 736	414 675	438 320

* Considered conventional resources because uranium is the main commodity of interest.

Inferred conventional resources by production method

(in situ tonnes U*)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	4 896	29 144	77 137	83
Open-pit mining (OP)	0	0	2 849	2 849	91
In situ leaching acid	280 849	460 606	470 777	470 777	89
Co-product and by-product	0	1 871	1 871	1 871	91
Total	280 849	467 373	504 641	552 634	

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	4 896	29 144	77 137	83
Conventional from OP	0	1 871	4 720	4 720	91
In situ leaching acid	280 849	460 606	470 777	470 777	89
Total	280 849	467 373	504 641	552 634	

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	280 849	462 477	472 648	472 648
Metasomatite	0	4 896	29 709	72 845
Phosphate*	0	0	0	4 857
Lignite-coal*	0	0	2 284	2 284
Total	280 849	467 373	504 641	552 634

* Considered conventional resources because uranium is the main commodity of interest.

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
85 221	113 166	114 696

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
191 880	219 380	N/A

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining[1]	21 618	0	0	21 618	0
Underground mining[1]	42 549	0	0	42 549	0
In situ leaching	274 131	22 808	19 477	316 416	21 819
Total	338 298	22 808	19 477	380 583	21 819

1. Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	42 109	0	0	42 109	0
Heap leaching*	440	0	0	440	0
In situ leaching	274 131	22 808	19 477	316 416	21 819
U recovered from phosphate rocks	21 618	0	0	21 618	0
Total	338 298	22 808	19 477	380 583	21 819

* A subset of open-pit and underground mining since it is used in conjunction with them.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	274 131	22 808	19 477	316 416	21 819
Metasomatite	42 549	0	0	42 549	0
Phosphate	21 618	0	0	21 618	0
Total	338 298	22 808	19 477	380 583	21 819

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
10 736	55	-	-	6 068	31	2 673	14	19 477	100

Uranium industry employment at existing production centres

(person-years)

	2017	2018	2019	2020
Total employment related to existing centres*	25 224	20 801	20 684	21 186
Employment directly related to uranium production	8 120	7 822	7 242	7 060

* NAC Kazatomprom employees.

Mid-term production projection

(tonnes U/year)

2021	2022	2025	2030	2035	2040
21 819	22 039	27 463	32 587	22 240	14 869

Mid-term production capability

(tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
28 000	29 000	28 000	29 000	26 000	29 000	26 000	29 000

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
14 000	22 000	14 000	23 000	9 000	13 000	9 000	14 000

Malawi*

Uranium exploration and mine development

Historical review

Historical studies indicate that economically recoverable resources of uranium and coal only occur within the Kayelekera area of Malawi. Coal is present in the project tenement area in two deposits: the Nkhachira deposit (850 000 tonnes, recoverable by open-pit and underground mining) and the Kayelekera deposit. Uranium is associated with coal at the Kayelekera deposit, and due to this association, coal is therefore unavailable for commercial extraction (moreover, this coal is of very low quality).

The Kayelekera deposit was discovered in the early 1980s by the Central Electricity Generating Board of Great Britain (CEGB). Kayelekera is a sandstone-hosted uranium deposit, located close to the north tip of the North Rukuru Basin. This basin contains a thick (at least 1 500 m) sequence of Permian Karoo sandstones preserved in a semi-graben about 35 km to the west of and broadly parallel to the Lake Malawi section of the East African Rift System. Mineralisation lies within the uppermost 150 m of the Muswanga Member, which is the upper part of the Karoo Formation. The Muswanga Member consists of eight separate arkose units with intervening silty mudstones in an approximate 1:1 ratio. Such a succession is indicative of cyclic sedimentation within a broad, shallow, intermittently subsiding basin. The arkose units contain most of the uranium mineralisation. They are on average about 8 m thick, are generally coarse grained and poorly sorted, and contain a high percentage of fresh, pink feldspar grains. The basal arkose units are usually a quartz-feldspar pebble conglomerate. Coffinite has been identified as the principal uranium-bearing species and it occurs together with minor uraninite. Near-surface weathering of primary ore has produced a zone of oxide ore characterised by yellow and green secondary uranium minerals (meta-autunite and boltwoodite). Approximately 40% of the total ore occurs within reduced arkose, 30% within oxidised arkose, 10% in mixed arkose, and 20% is considered of the mudstone type.

Extensive drilling from 1982 to 1988 defined initial inferred resources of 9 800 tU at an average grade of 0.13% U. From 1989 to 1992, geotechnical, metallurgical, hydrological and environmental activities were conducted, as well as a feasibility study, to assess the viability of a conventional open-pit mining operation. This work was completed in 1991 at a total cost of USD 9 million. The CEGB study concluded that the project was uneconomic using the mining model adopted and the low uranium prices of that time and so the project was abandoned in 1992.

In 1998, Paladin Resources Ltd (Paladin Energy Ltd as of 1 February 2000) acquired an interest in the Kayelekera Project through a joint venture with Balmain Resources Ltd, which at that time held exploration rights over the project area. Engineering and financial evaluation work indicated a positive outcome for the project. In 2004, additional drilling was completed to improve confidence in resource estimates, and the pre-feasibility study was updated. Resource drilling and bulk sample drilling for metallurgical test work was completed in 2005 and a bankable feasibility study was then undertaken. Paladin purchased Balmain's remaining stake in the project in 2005 and became the sole owner.

* Report prepared by the NEA/IAEA, based on previous Red Books, company reports and input from the Government of Malawi.

Uranium exploration increased as a result of expanding resources at the Kayelekera mine and the potential for discovery of additional deposits in a similar geological setting in the Karoo Group sedimentary rocks. Since 2010, Paladin Energy has completed exploration drilling in areas to the north-west and south of the mine area with objectives of extending the existing orebody, as well as identifying and evaluating new ore bodies, including Mpata to the east and Juma to the south.

The Livingstonia uranium project is a joint venture between two Australian companies, Resource Star and Globe Metals and Mining. The geological setting is very similar to that of Kayelekera. In 2006, Globe drilled 94 holes totalling 11 533 m. In July 2010, Resource Star drilled an additional 1 502 m in 13 holes to prove up a JORC compliant inferred resource of 7.7 million tonnes ore grading 0.0229% U. In 2013, Resource Star, the operator of the Livingstonia Project, reported that thickened zones of mineralisation are open to the north-east, and the sparse drilling in the southern zone increases potential for additional mineralisation being defined. The mineralisation is also open to the north, where the project adjoins tenements owned by Paladin Energy Ltd.

Another potential uranium resource is the Kanyika Niobium Project held by Globe Metals. Uranium is an important by-product in the complex niobium and tantalum ore in a pegmatite quartz vein, hosted in Proterozoic felsic schists. Niobium and tantalum products would be produced with uranium as a by-product. In 2011-2012, Globe Metals & Mining continued development of the Kanyika deposit. Total drilling, reverse circulation and diamond drilling, amounted to 40 540 m. As of December 2012, total resources amount to 68.3 Mt of ore at average grade of 0.28% Nb_2O_5, 0.0135% Ta_2O_5 and 0.0067% U (4 550 tU). Globe Metals & Mining submitted an environmental impact assessment for the Kanyika Niobium Project for public review in May 2012.

Recent and ongoing uranium exploration and mine development activities

The anticipated early approval by the Department of Mines of applications for five exclusive prospecting licences (EPLs), covering areas north, south and east of the Kayelekera mine, which would have enabled exploration activity to commence in July 2015, did not occur. The government of Malawi imposed a moratorium on applications and grants of all mining and exploration tenements until it introduces a new cadastral system and a new minerals act. As a result, Paladin suspended exploration activities in Malawi until there is clarity on the provisions of the new mining code and its EPL applications have been granted.

In 2013, Global Metals & Mining approved a demonstration plant to further optimise process design and reduce project risk in the Kanyika Niobium Project. The focus of the pilot plant is to validate bench-scale testing results obtained during the optimisation phase of the Kanyika Definitive Feasibility Study, and also to validate engineering data for plant design. The Kanyika bulk sample is located at the Guangzhou Research Institute of Non-Ferrous Metallurgy (China) and the pilot plant is in progress. The mineral concentrate produced from this pilot plant exercise will be used for further downstream metallurgical testing and production of marketing samples.

In February 2018, Globe started a feasibility study aimed at updating and finalising the technical components of the engineering programme in order to support project funding initiatives. On 11 July 2018, Globe published an updated Mineral Resource Estimate for the Kanyika Niobium Project, calculated in accordance with 2012 JORC guidelines. The resources are unchanged from the previous Mineral Resource Estimate published on 7 January 2011.

In January 2019, Globe Metals announced that it had finalised the feasibility study, including revision of the mineral resource estimates, mining, metallurgical studies, processing, engineering design and infrastructural support. It obtained updated capital and operating cost estimates and updated its financial model. However, Globe Metals is not yet in a position to finalise the financial model and the key outcomes of the project, due to the current uncertainty associated with the status of the mining law in Malawi, and to the status of negotiations between Globe Metals and the Government on the Development Agreement.

In March 2020, the Australian company Lotus Resources Ltd completed the acquisition of the Kayelekera Project from Paladin Energy and announced an increase in JORC compliant resources to 1 580 tU of measured resources, including run of mine stockpile, 10 445 tU of indicated resources, and 2 428 tU of inferred resources, including a low-grade stockpile. The average grade is 0.053 %U and the figures indicate an assumed 0.026%U cut-off. Resources are reported as in situ.

In June 2021, Lotus Resources Ltd announced the start of a 5 000 m reverse circulation drilling programme at Kayelekera. Drilling will test airborne radiometric anomalies located within 3 km of the existing processing facility with the objective of increasing the current 14 years of mine life.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2021 Malawi's total recoverable identified resources were 16 272 tU. This is based on resources at three locations: Paladin's Kayelekera operating mine (11 720 tU), Resource Star's Livingstonia deposit (1 822 tU) (both sandstone deposits), and Globe Metal's Kanyika niobium deposit (2 730 tU), where uranium will be produced as a by-product. During 2019 and 2020, recoverable uranium resources increased by 1 995 tU, as a result of a new resource evaluation completed by Lotus Resources Ltd.

Uranium production

Historical review

The Kayelekera mine is located in the Karonga district of the northern region of Malawi, about 600 km by road from the capital city of Lilongwe. Transport of the first product to Walvis Bay, Namibia, via Zambia, took place on 17 August 2009. Uranium production is by open pit with an annual production of 1 270 tU planned with a mine life of nine years.

Uranium is recovered using a solvent extraction process, with sulphuric acid as the lixiviant and sulphur dioxide/air mixture as the oxidant. The plant utilises a resin-in-pulp (RIP) process which is a first in the Western world for uranium production. Expected uranium mill recovery is 90%. Production was hampered in 2009 and 2010 by technical problems with the RIP process. In addition, land slip problems in 2010 resulted in remediation work being implemented and made it necessary to relocate certain parts of the plant and machinery.

In 2013, the Kayelekera mine made progress on cost reductions, mainly on the acid supply front, where the project became acid independent through a number of measures. Improvements included increases in on-site acid production and the addition of the nano-filtration plant, which assisted with acid recycle. In addition to acid management, other improvements were realised in the milling, leach and RIP efficiencies, particularly with completion of modifications in the RIP section.

In 2014, the site was placed on care and maintenance. Following a period of reagent run-down, processing was completed in early May 2014. This was expected to cost about USD 12 million per year, ongoing, compared with operating losses of double of that. It is expected that production will recommence once the uranium price provides a sufficient incentive (circa USD 75/lb U_3O_8; USD 195/kgU) and grid power supply is available on-site to replace the existing diesel generators with low-cost hydroelectricity.

In 2013 and 2014, the Kayelekera mine produced 1 132 tU and 369 tU, respectively. Once uranium prices offer sufficient incentive to restart, production, with some RIP/elution upgrades, is expected to be up to 1 270 tU per year.

Status of production facilities, production capability, recent and ongoing activities and other issues

In 2020, Lotus Resources Ltd conducted a restart scoping study of the Kayelekera uranium mine. Two scenarios were considered: treating only high-grade material and treating the medium-grade stockpiles at the end of the life of mine after high-grade material is exhausted.

The first scenario involves an 8-year life of mine, producing 6 300 tU with average head grade of about 0.076% U. The second scenario considered a 14-year life of mine, producing 9 150 tU, with treatment of stockpiles from year 8 (with an average head grade of about 0.0580% U).

Under the first scenario, production costs would be USD 85.8/kgU during years 2-6, with average annual production of 920 tU. Lotus Resources noted that multiple opportunities were identified to further reduce these costs, including: upgrading of feed materials; improved options around power supply; acid recovery; and optimised tailings disposal options.

The restart of Kayelekera would require an initial capital cost of USD 50 million.

Ownership structure of the uranium industry

Two Australian companies, Paladin Energy and Resource Star, used to be active in Malawi in the primary uranium sector.

Paladin held an 85% interest in the Kayelekera Project through its subsidiary company Paladin (Africa) Limited. The remaining 15% is held by the Republic of Malawi according to terms of the Development Agreement signed in 2007. Paladin had supplemented ongoing mining with extensive exploration activities aimed at growing its resource base in Malawi. However, in June 2019 Paladin Energy agreed to sell its 85% interest in the mine to Hylea Metals subsidiary Lotus Resources Ltd (65%) and to Chichewa Resources (20%) for AUD 5 million. Paladin will receive a 3.5% royalty based on revenues derived from future production at Kayelekera, capped at AUD 5 million.

On 13 March 2020, Paladin completed the sale of its 85% interest in Paladin (Africa) Ltd to Lotus Resources (65%) and Lily Resources Pty Ltd (20%). Lotus, formerly Hylea Metals Limited, holds 76.5% of the shares in Lily with Kayelekera Resources Pty Ltd holding 23.5%, giving Kayelekera Resources Pty Ltd an indirect 20% interest in the Kayelekera Project. The remaining 15% of shares in Paladin (Africa) Ltd are held by the Malawi government.

In 2010, Resource Star signed a joint venture agreement with Globe Metals and Mining over their Livingstonia Project, with Resource Star managing work and earning up to 80% equity. In May 2012, Resource Star announced that it would acquire 100% of the Livingstonia Project from Globe. The Malawi authorities approved the transfer of the exploration licence to Resource Star in November 2012, at which time Resource Star applied to the Malawi authorities for a two-year extension to the term of the Livingstonia tenement. Global Metals is also involved in rare earth exploration with significant uranium by-product potential.

Employment in the uranium industry

Paladin employed 759 people at the Kayelekera mine in 2012, of which 118 were expatriates and 68, or 9%, were female. Information on recent employment is not available.

Future production centres

Globe Metals & Mining submitted the environmental impact assessment for the Kanyika Niobium Project for public review in May 2012. According to Globe, the aim of the project is to produce niobium and tantalum products with potential production of uranium and zircon. Uranium would be produced as a by-product at a nominal rate of 80 t $Na_2U_2O_7$ (ammonium di-uranate) per year (60 tU/yr). Mining will involve the extraction of ore from a single open pit at a rate of 1.5 million tonnes per annum using conventional open-pit drill and blast, followed by truck shovel load and haul. The final open pits are expected to have dimensions in the order of 250 m in width, 2.2 km in length (north-south) and 130 m in depth. The project will produce approximately 52 million tonnes of solids to tailings over the mine life (estimated in excess of 20 years).

As of January 2019, Globe Metals could not set a time frame for when mining and processing at Kanyika could start.

Uranium production centre technical details

(as of 1 January 2015)

	Centre #1	Centre #2
Name of production centre	Kayelekera	Kanyika
Production centre classification	Idled	Planned
Date of first production (year)	2009	NA
Source of ore:		
Deposit name(s)	Kayelekera	Kanyika
Deposit type(s)	Sandstone	Intrusive
Recoverable resources (tU)	9 150	2 730
Grade (% U)	0.058	0.008
Mining operation:		
Type (OP/UG/ISL)	OP	OP
Size (tonnes ore/day)	4 000	6 000
Average mining recovery (%)	75	NA
Processing plant:		
Acid/alkaline	Acid	NA
Type (IX/SX)	SX	NA
Average process recovery (%)	80	NA
Nominal production capacity (tU/year)	1 270	60
Plans for expansion (yes/no)	Yes	NA
Other remarks	Ramp up to 1 460 tU/yr	By-product

Environmental activities and socio-cultural issues

There are no updates for the current reporting period.

Uranium requirements

Malawi has no plans for nuclear power.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

All mining activities are under the control of the Department of Mines of the Ministry of Natural Resources with environmental matters falling under the Department of Environmental Affairs in the same ministry. However, in common with many developing countries, Malawi has no specific legislation or a regulation relating to uranium, but it is working in co-operation with the International Atomic Energy Agency to develop appropriate legislation. In 2011, the National

Assembly passed an atomic energy bill, which is the first step in the introduction of comprehensive legislation to provide for adequate protection of people as well as the environment against harmful effects of radiation, nuclear material and radioactive materials.

The government is committed to putting in place policies that will attract private sector participation in the exploration, exploitation, processing and utilisation of Malawi's mineral resources. To this end, in March 2013, the Mines and Mineral Policy of Malawi was developed by the Malawi government. The government recognises that the minerals sector has significant potential to contribute towards the rapid economic growth and development of the country. The policy seeks to stimulate and guide private mining investment by administering, regulating and facilitating the growth of the sector through a well-organised and efficient institutional framework. The government will also intensify provision of extension services to the artisanal and small-scale miners and women miners. The goal of the Mines and Minerals Policy is to enhance the contribution of mineral resources to the economy of the country so as to move from being an agro-based to mineral-based economy.

On 14 December 2018, the National Parliament of Malawi passed a new bill (Mines and Minerals Bill 2018) to replace current legislation. For the New Act to come into force it must receive presidential assent, which has not yet occurred.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	7 722	9 778	81
Co-product and by-product	0	0	0	2 205	60
Total	0	0	7 722	11 983	

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	7 722	9 778	81
Unspecified	0	0	0	2 205	60
Total	0	0	7 722	11 983	

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	7 722	9 778
Intrusive	0	0	0	2 205
Total	0	0	7 722	11 983

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	1 822	3 764	80
Co-product and by-product	0	0	0	525	60
Total	0	0	1 822	4 289	

Inferred conventional resources by processing method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional OP	0	0	1 822	3 764	80
Unspecified	0	0	0	525	60
Total	0	0	1 822	4 289	

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	1 822	3 764
Intrusive	0	0	0	525
Total	0	00	1 822	4 289

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2017	2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining	4 217	0	0	0	4 217	0
Total	4 217	0	0	0	4 217	0

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2017	2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional OP	4 217	0	0	0	4 217	0
Total	4 217	0	0	0	4 217	0

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2017	2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	4 217	0	0	0	4 217	0
Total	4 217	0	0	0	4 217	0

Short-term production capability

(tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	NA	NA	0	0	NA	NA

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	NA	NA	0	0	NA	NA

Mali*

Uranium exploration and mine development

Historical review

The French Atomic Energy Commission explored for uranium in Mali in the Adrar des Iforas region, a large crystalline geological province along the border with Senegal, between 1954 and 1956. Indications of uranothorianite and thorianite were discovered in large pegmatite lenses enclosed in highly metamorphosed hornblende- and pyroxene-schists of the Suggarian sequence. Numerous granites were also studied in the area, but only younger granites showed anomalous radioactivity, probably because of the presence of monazite as an accessory mineral.

Under an agreement with the government of Mali, German company Krupp carried out a reconnaissance survey in the eastern part of Mali in 1970 with no positive results. In 1971, Germany's Institute for Geosciences and Natural Resources (BGR) carried out a hydrogeochemical and radiometric reconnaissance survey in the western Kayes region of the country. Some anomalies were found but their character did not encourage further activities. In 1974, Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC) initiated an exploration project in the Adrar des Iforas covering parts of the Taoudeni sedimentary basin.

In 1976, the Compagnie Générale des Matières Nucléaires (COGEMA) started exploration in the areas of Kenieba, Kayes, Bamako, Sikasso, Hombori, Douentza and Taoudenni. This work included airborne radiometric surveys in Kenieba and Taoudenni, and geophysical exploration (including drilling) in Kenieba (Faléa and Dabora). COGEMA ended its exploration project in 1983 and PNC limited its activities to a small area of 20 km^2. PNC continued work through the first quarter of 1985, using radon emanometry and very-low-frequency electromagnetic survey methods over an area of 14 km^2, and then ended its activities in the second quarter of 1985.

From 2007 to 2008, several other companies conducted uranium exploration in Mali. In 2007-2008, Australia's Oklo Uranium Ltd. conducted uranium exploration over the Kidal area, part of the underexplored north-eastern part of Mali. Exploration covered the Adrar des Iforas, which is considered prospective for surficial paleo-channel-hosted uranium, alaskite/pegmatite, and vein-hosted uranium, and contains occurrences of uranium, gold, copper-lead-zinc and manganese. Target identification has been undertaken in the project area with 47% of an airborne geophysical survey completed in 2007. In 2008, potential uranium anomalies were located and tested with ground spectrometry, geochemical sampling and drilling.

At Faléa, COGEMA first discovered substantial uranium and copper values in the late 1970s, but the project has not advanced because of the prevailing low commodity prices. Exploration conducted since 2008 by Rockgate Capital Corp. and Delta Exploration Inc. focused on defining and expanding these initial results.

The mineralisation at the Faléa project occurs within the Neoproterozoic to Carboniferous sedimentary sequence of the Taoudeni Basin, a shallow interior sag basin with flat to very shallow dips. Faléa is located along the southern edge of the western province of the Taoudeni Basin. In the previous editions of the Red Book, the Faléa deposit was classified as a sandstone-type deposit. Now it is classified as an unconformity-type deposit. With a few exceptions, mineralisation has been confined to the flat-lying Kania Sandstones unit, as well as within the units immediately above and below it. The distance from the surface to the mineralised horizon varies between

* Report prepared by the NEA/IAEA, based on previous Red Books and company reports.

31.5 m to more than 350 m below the surface. The first mineralising event related to ore genesis is believed to have deposited copper (mostly in the form of chalcopyrite) and silver. The copper mineralisation occurs as disseminations, primarily within the Kania Sandstones, around which halos of uranium minerals precipitated (mostly as pitchblende and coffinite), thus acting as a chemical trap (reductant) for uranium mineralisation.

From January to August 2011, 160 diamond drill holes totalling 45 691 m focused on resource definition in the North Zone and initial exploration drilling at Bala, south of the Central Zone, East Zone and Road Fault. The programme resumed in October 2011, continuing through July 2012, and comprised 398 diamond drill holes totalling 88 350 m. Drilling continued to infill and step-out in the North Zone and expanded north into the Bodi Zone. An additional 44 diamond drill holes were completed in the East Zone and 19 more in the Central Zone as part of an expanded resource definition programme.

In October and November 2012, a total of 15 936 m were completed in 66 diamond drill holes located in the Bodi and North Zone areas. Almost all work to date has been completed on the Faléa Permit.

Recent and ongoing uranium exploration and mine development activities

In January 2014, Denison Mines Corp. concluded the purchase of Rockgate and commenced work on the Faléa project, including a detailed project review and reinterpretation of existing exploration data and comprehensive internal economic study. Results have shown the project to be uneconomic under current metal prices; however, the potential could improve if additional resources are discovered.

A versatile time-domain electromagnetic (VTEM) survey, including magnetic and radiometric surveys, was completed in March 2015. A small ground follow-up programme was completed in June 2015, including soil sampling and radiometric prospecting.

In June 2016, GoviEx Exploration (Canada) acquired the Faléa project from Denison Mines. The project includes three exploration licences, Bala, Faléa and Madini.

In 2017, GoviEx conducted a geophysical survey over the Faléa area. Radon measurements were carried out by Radon Ex. Ltd. New targets have been defined, which have to be developed and are likely to increase the resources. No drilling was completed in 2017-2018.

In 2018, GoviEx applied for new exploration licences for the Bala and Madini areas and renewed the Faléa licence for a second term.

As of 1 January 2019, nine uranium exploration permits had been granted to six exploration companies in Mali. However, because of the rebellion in the north-eastern part of the country, exploration activities are only being undertaken in the western part of the country.

In 2019, ASTER images of the Faléa area were interpreted for the identification of new exploration targets.

In May and June 2020, soil and termitaria sampling were completed on the Faléa project. The geochemical results highlighted significant gold anomalies, in addition to already known U, Cu and Ag anomalies.

During the fourth quarter of 2020, GoviEx conducted a core sampling and geophysics programme, which identified a significant correlation between the Birimian geology, the fault structures and the geophysical chargeability anomalies in relation to gold mineralisation.

In January 2021, GoviEx announced a 6 000 m air core drilling programme to test the gold potential associated with soil anomalies. No drilling for uranium exploration was completed in 2020 and 2021.

Exploration permits

As of 20 December 2021, four uranium exploration permits have been granted to two exploration companies in Mali. However, because of the rebellion in the north-eastern part of the country, exploration activities are only being undertaken in the western part of the country.

Permits	Area (km^2)	Company	Location
Arafat-south	400	Singkind Mines Mali Sarl	Southern part
Bala	125	Delta Exploration Mali Sarl/GoviEx Uranium Inc.	Western part
Faléa	75		
Madini	67		

Uranium resources

Identified conventional resources

An updated NI 43-101 compliant resource estimate was reported for the Faléa project in October 2015 using a cut-off grade of 0.03% U3O8 (0.025% U) resulting in total indicated resources of 6.88 Mt at an average grade of 0.098% U, 0.161% Cu, 72.8 g/t Ag and inferred resources of 8.78 Mt at an average grade of 0.059% U, 0.20% Cu, 17.3 g/t Ag. Total in situ identified resources amounted to 11 846 tU, which includes 6 692 tU indicated and 5 154 tU inferred (no change compared to the 2018 edition of the Red Book).

Recent metallurgical test work and engineering have confirmed consistent recoveries of uranium, silver, and copper and hence all of these metals that may be expected from mining. A pre-feasibility study has been initiated based upon the results above, together with an enhanced understanding of the orebody and possible mining and metallurgical solutions.

Environmental activities and socio-cultural issues

On 26 April 2010, Rockgate announced that it had commissioned Golder Associates to conduct environmental and social baseline studies on the Faléa project. In January 2014, Denison took over Rockgate.

Uranium exploration and development expenditures and drilling effort – domestic

(USD)

	2016	2017	2018	2019	2020
Industry exploration expenditures	386 942	390 000	354 000	298 000	30 000
Total expenditures	386 942	390 000	354 000	298 000	30 000

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	6 692	6 692	NA
Total	0	0	6 692	6 692	NA

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unconformity*	0	0	6 692	6 692
Total	0	0	6 692	6 692

* Previously classified as a sandstone-type deposit.

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	5 154	5 154	NA
Total	0	0	5 154	5 154	NA

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unconformity*	0	0	5 154	5 154
Total	0	0	5 154	5 154

* Previously classified as a sandstone-type deposit.

Mauritania*

Uranium exploration and mine development

Historical review

The first uranium exploration project in Mauritania was carried out in 1959 by France's Atomic Energy Commission in the Ogmane anticline.

In 1972, following the discovery of surficial-type uranium deposits in Western Australia, uranium exploration was initiated in the Reguibat Range by Total Compagnie Française de Pétrole (in a joint venture with the Société Mauritanienne de Recherches Minières, the French Atomic Energy Commission, and Tokyo Uranium Development Company). The two exploration permits covered a total area of 164 000 km², divided into four blocks (Chami, Bir Hoghrein, Nouadhibou and Ghallamane). In 1975, the total area was reduced to five blocks totalling 41 000 km², and these joint ventures were modified after the founding of French Minatome SA and Compagnie Générale des Matières Nucléaires.

These joint ventures held the areas up to 1983. Work on the permits was carried out between 1972 and 1975 and again in 1981 and targeted the evaluation of surficial-type deposits (Reguibat Range), as well as occurrences in the Precambrian basement, where radioactive anomalies were found associated with syenites and granites (Bir En Nar, Tigismat, Tenebdar). In 1983, all uranium exploration activities were suspended.

In December 2007, Australia's Forte Energy NL completed its first drilling programme in Mauritania, a 4 006 m reverse circulation programme of 41 holes of 50-150 m depth. The drilling was carried out in the Bir En Nar area of the Zednes region and followed up on high-grade results previously obtained. Downhole radiometric logging results indicated numerous high-grade uranium intersections, including 1.55 m at 18 280 ppm U (1.83% U). The results of drilling a second group of 21 holes yielded up to 6 310 ppm U (0.63% U) over 1 m, and 576 ppm U (0.058% U) over 19 m.

In November 2006, the United Kingdom's Alba Mineral Resources, along with Mauritania Ventures Limited, started to investigate the uranium potential of areas located in northeast Mauritania. The area is considered prospective for unconformity-type uranium mineralisation. The permits cover significant areas of an unconformable contact between Early Proterozoic reworked granitic terrain and overlying sediments of Late Proterozoic to Carboniferous age. Airborne geophysics, flown on behalf of the Mauritanian government, revealed radiometric anomalies within a mapped, organic-rich unit near the base of this sedimentary sequence, and coincident with its intersection with large, deep penetrating crustal shear structures. Uranium mineralisation is known in the north and northwest part of the permit area, hosted in granites and rhyolites cut by these shear structures. On 3 November 2010, Alba Mineral Resources was notified that the mining authorities in Mauritania had withdrawn the licence, citing a lack of additional exploration activity.

Mauritania's Ministry of Petroleum, Energy, and Mines began in 2006 to implement a project, "*Projet de Renforcement Institutionnel du Secteur Minier (PRISM-II)*", with the US Geological Survey to define the mineral resource potential of the country. It included delineation of areas permissive for calcrete-hosted, granite-hosted vein/shear, alkaline intrusive-hosted, unconformity-related,

* Report prepared by the NEA/IAEA, based on previous Red Books and company reports.

quartz pebble conglomerate-hosted, phosphate, sandstone-hosted and red bed-type uranium deposits. The results were published in 2013 (USGS Open-File Report 2013-1280).

Recent and ongoing uranium exploration and mine development activities

Forte Energy NL, based in Australia, holds several uranium exploration licences in Mauritania, including for the A 238 and Bir En Ar areas.

The A 238 and Bir En Ar uranium prospects are associated with granites near Bir Moghrein in the north of Mauritania. At the A 238 prospect, the main zone of mineralisation extends over a strike length of 1.75 km with mineralisation extending down to over 250 m from the surface with widths of over 60 m within 50 m of the surface.

Following the positive results of the 2009/10 reverse circulation (RC) drilling, a further RC drilling programme of around 11 300 m commenced in October 2010, focusing initially on anomaly A 238. Preliminary results from A 238 indicated the potential for a shallow, large-volume, medium-grade deposit. A total of approximately 10 450 m of RC and diamond core drilling has been carried out, resulting in an announcement in June 2011 of initial JORC code compliant U resources for A 238 of 26.5 Mt at 217 ppm U (0.0217% U) for 5 730 tU (85 ppm U cut-off; 0.0085% U).

After completing a further 63 holes (8 567 m) of RC drilling in 2011/12, an updated JORC resource was announced in April 2012 for A 238. The deposit remains open along strike.

Deposit	Resource category	Average grade (ppm U)	Tonnes of U
A 328	Inferred	199 (0.02% U)	9 000
Bir En Nar	Indicated Inferred	751 (0.0751% U) 488 (0.0488% U)	385 385
Total	Indicated Inferred	751 (0.0751% U)* 204 (0.0204% U)*	385 9 385

* Weighted-average grade by proportional amount of tU.

In 2015, Forte was delisted and its leases in Mauritania expired.

Australia’s Aura Energy owns the Tiris project (previously known as the Reguibat project), which comprises several laterally extensive developments of calcrete uranium mineralisation in northern Mauritania. Between November 2010 and February 2011, Aura completed a drilling programme which covered all of Aura’s wholly owned permits, as well as its joint venture permits, which totalled over 9 100 m in 2 022 holes.

A JORC code compliant uranium resource, based on these drilling results, was released in 2012 (85 ppm U cut-off):

Deposit	Resource category	Average grade (ppm U)	Tonnes of U
Reguibat	Indicated Inferred	254 (0.0254% U) 284 (0.0284% U)	770 18 077
Total	Indicated + Inferred	283 (0.0283% U)*	18 847

* Weighted-average grade by proportional amount of tU.

In 2014, Aura conducted a scoping study that confirmed that Reguibat could be a robust project with shallow mineralisation that could be upgraded through simple beneficiation to high-grade leach feed. The study indicated that some 4 200 tU could be produced over an initial mine life of 15 years, using only 20% of the project's known total mineral resource. The project would require a capital investment of about USD 50 million and would have an operating cost of USD 30/lbU_3O_8 (USD 78/kgU), and with a mine-life average production of 290 tU/yr.

Additionally, extensive radiometric surveys allowed Aura to estimate an exploration target of an additional 19 000 tU, inferring a total mineral resource target of around 38 000 tU at Reguibat.

In 2015, the project progressed to the definitive feasibility study (DFS) stage. The Tiris uranium project has an initial production profile of up to 1 million lb U_3O_8 (385 tU) per annum, with the scoping study indicating an average life of mine over 15 years.

In 2015-2016, Aura continued to conduct test-work and validation work aimed at defining optimal methods for the recovery of uranium. Additional verification/validation programmes were completed, including downhole gamma logging, disequilibrium test-work, trenching of the mineralisation and detailed ground radiometric surveying.

Aura highlighted the very fine nature of the uranium-bearing mineral, carnotite. However, this fine-grained character, together with the high, short-range grade, presents challenges in sampling. Carnotite tends to occur as small lenses, nuggets and coatings in or on the calcrete. Its distribution varies from deposit to deposit. This variability requires understanding and management in upgrading resources to measured and indicated status. In general, variability reduces as sample size increases, and for that reason, the 2015 drilling employed a larger diameter drill bit than that used in the earlier resource drilling programmes, resulting in a 50% greater sample size. However, even with the larger sample size, grade variability has still been relatively high. To test the effectiveness of gamma logging at Tiris, 63 holes that had been drilled and cased in 2015 were gamma logged. Results of this work were positive, and Aura is now using down gamma logging for its resource upgrade work.

In 2016, the Tiris project progressed to the feasibility study stage. In 2017, Aura continued the Tiris feasibility study, including the following activities: mining lease application, resource definition, geophysics for the definition of water resources and drilling, metallurgical progress on test-work, simulation and flowsheet development, early-stage engineering, completion of an Environmental and Social Impact Assessment (ESIA), and a community consultation process.

In 2017, a programme of ground radiometric surveying was carried out over all Tiris uranium resource zones as well as priority exploration targets, such as Hippolyte South, that warrant drilling. The surveys were conducted on lines spaced 20 m apart. A programme to increase the proportion of Measured and Indicated Resources commenced in May 2017. This involved an extensive drilling programme on a 50 m x 50 m pattern with each hole being gamma logged. A proportion of the holes have been drilled by large diameter triple tube diamond drilling and the core was chemically assayed to validate the downhole gamma logging and to obtain density data throughout the zones drilled.

The ESIA was completed in 2017 by Earth Systems. The ESIA pays attention to issues of radiation exposure and the security of the yellowcake product. Best practice guidelines from the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP) have been used, complementing the applicable Mauritanian regulations and guidelines. The ESIA was approved by the Mauritanian government on 5 October 2017.

A programme of trenching was undertaken within the Lazare North and Lazare South deposits in April 2018. A total of 11 trenches were completed, with 8 in the Lazare South and 3 in the Lazare North deposits. Trenches were dug to a depth of 4 m. The focus of this programme was to collect representative samples for detailed test-work.

On 27 August 2021, Aura released the results of a new resources estimate of the Tiris East deposits. The new resource estimate incorporates drill holes on the Sadi South Zone, not included in earlier resource estimates. This has resulted in a 2 080 tU increase in the Tiris East resource.

Tiris West Resources (at a 85 ppm U cut-off – 2011 estimate)

Deposit	Category	Ore (Mt)	Grade (%U)	U (tU)
Agouyame	Inferred	2.6	0.0178	462
Ferkik East	Inferred	4.5	0.0204	923
Ferkik West	Inferred	11.9	0.0280	3 385
Total Tiris East	Inferred	19.0	0.0251	4 770

Tiris East Resources (at a 85 ppm U cut-off – 2021 estimate)

Deposit	Category	Ore (Mt)	Grade (%U)	U (tU)
Hippolyte	Measured	5.7	0.0191	1 077
	Indicated	6.5	0.0184	1 192
	Inferred	7.4	0.0238	1 769
Hippolyte South	Indicated	4.8	0.0163	769
	Inferred	3.1	0.0149	462
Hippolyte West	Inferred	6.3	0.0254	1 615
Lazare North	Measured	1.1	0.0241	269
	Indicated	10.6	0.0194	2 077
	Inferred	3.9	0.0178	692
Lazare South	Measured	3.4	0.0203	692
	Indicated	2.6	0.0186	500
	Inferred	9.1	0.0181	1 654
Sadi	Indicated	4.5	0.0204	923
	Inferred	14.9	0.0226	3 346
Total Tiris East	Measured	10.2	0.0200	2 038
	Indicated	29.0	0.0188	5 461
	Inferred	44.7	0.0213	9 538

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

In 2012, Forte released a JORC code compliant U resource for the A 328 and Bin En Ar deposits. Based on an 85 ppm U cut-off (0.0085% U), global resources for the A 328 and Bin Ar deposits totalled 385 tU in the indicated category, and 9 385 tU in the inferred category (in situ resources).

In 2021, Aura released a new JORC code compliant resource estimation including the Sadi South Zone. Based on an 85 ppm U cut-off (0.0085% U), global resources of for the Tiris project total 7 499 tU in the measured + indicated categories, and 14 308 tU in the inferred category (in situ resources).

Undiscovered conventional resources (prognosticated and speculative resources)

Strong radiometric anomalies exist in Mauritania, similar to anomalies occurring with the known resources at Tiris. Aura's exploration has largely focused on radiometric anomalies defined by regional airborne radiometric surveys. In 2016, Aura estimated an additional potential of 19 000 tU in the Reguibat area.

Uranium production

In 2014, Aura completed the Reguibat scoping study.

Mineralisation occurs largely within 3-4 m of the land surface, in gravels and weathered granite. Most of the mineralisation occurs as single sheets with little or no cover. The material is largely unconsolidated and can be readily excavated by diggers or scrapers without blasting. The overlying waste consists of loose windblown sand. The strip ratio is anticipated to be approximately 0.25:1.

Simple washing and screening tests on the ore yielded encouraging results. Wet screening at 75 µm resulted in the rejection of 80% by weight with the retention of 91% of the uranium into the screen undersize. This represents a sevenfold upgrade factor from the 334 ppm U (0.0334% U) resource grade. These results may be explained by the extremely fine size and ready liberation of the uranium mineral, carnotite, and the large difference in particle size distribution between the carnotite and the bulk of the host rock minerals. Following a series of encouraging small-scale preliminary tests, a standard leach test on -300 µm beneficiated material confirmed earlier results, with 92% uranium extraction within 4 hours and 95% after 8 hours.

The total estimated initial capital cost for engineering, procurement, construction, commissioning, start-up, and the owner's activities for the project is AUD 50 million. The life of mine unit operating cost estimate for the Reguibat project is estimated to be USD 30.3/lb U_3O_8 (USD 11.65/kgU). The planned operation will produce approximately 385 tU per year in years 2 and 3, followed by 250 tU for years 4-11, and 270 tU in years 12-15. The total uranium produced under these assumptions is approximately 3 850 tU over the 15-year mine life.

A feasibility study was undertaken in 2015, with a view to a simple truck and shovel mine on the eastern deposit, feeding an AUD 50 million plant, and production at about 400 tU/yr.

On 29 July 2019, Aura released the results of the Definitive Feasibility Study, which confirmed that the Tiris uranium project is a low cost and low operating cost development. The project is designed to support an open-pit mine, a 1.25 million tonnes of ore processing plant, and supporting infrastructure. The uranium mineralisation lies largely within 3 to 5 m of the surface in a relatively soft, free digging material containing patchy calcrete. Based on trenching and metallurgical test-work to date, the mineralisation does not require blasting before mining or crushing prior to beneficiation.

Three mining areas can be developed in a practical sequence to produce 310-425 tU per year through the processing plant for over 15 years. The processing facility will consist of three main sections: the beneficiation circuit, the uranium extraction circuit (alkaline leach – solid liquid separation – ion exchange), and the uranium purification and precipitation circuit. Uranium recovery is expected to be 86.1%. Vanadium could be recovered as vanadium pentoxide (V_2O_5) through a standard precipitation and purification process. Target production is 115 t V_2O_5 per year. The cost to develop and operate the mine for ten years has been estimated at USD 66 million, or USD 2.24 per tonne of material mined. Total operating cash cost will be USD 25.43/lb U_3O_8 (USD 66.1/kgU). The all-in sustaining cost (inclusive of royalties, LOM sustaining capital, insurances and product transport) will be USD 29.81/lb U_3O_8 (USD 77.5/kgU).

Two exploitation licences covering 390 km^2 were granted to Tiris Resources SA, a Mauritanian registered subsidiary of Aura Energy Limited, on 8 February 2019. The two licences cover the Eastern Tiris resources at Oued El Foule and Ain Sder. An application for a 38 km^2 exploitation licence remains pending over the smaller Western Tiris resource at Oum Ferkik.

In July 2021, Aura commenced Stage 2 exploration at the Tiris uranium project. The key results expected are:

- detailed results of the Tiris Opportunity Review with several items being considered to lower operating costs for the project;
- completion and outcomes of the net zero emission study;
- water drilling results continuing the 2019 findings;
- potential positive impact on the Tiris project operating cost from vanadium by-product recovery.

Ownership structure

The Tiris project is 85% owned by Tiris Resources SA, and 15% by the Mauritanian government through its agency Société Mauritanienne des Hydrocarbons et de Patrimoine Minier (SMH-PH).

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1
Name of production centre	Tiris
Production centre classification	Prospective
Date of first production (year)	NA
Source of ore:	
Deposit name(s)	Lazare N and S, Hippolyte
Deposit type(s)	Calcrete
Recoverable resources (tU)	3 105
Grade (% U)	0.0285
Mining operation:	
Type (OP/UG/ISL)	OP
Size (tonnes ore/year)	1.25 Mtpa
Average mining recovery (%)	NA
Processing plant:	
Acid/alkaline	Alkaline
Type (IX/SX)	IX
Size (tonnes ore/day)	NA
Average process recovery (%)	86.1
Nominal production capacity (tU/year)	315

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	6 450	6 450	86
Unknown	0	0	0	289	75
Total	0	0	6 450	6 739	85

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	6 450	6 450	86
Unknown	0	0	0	289	75
Total	0	0	6 450	6 739	85

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	0	289
Calcrete	0	0	6 450	6 450
Total	0	0	6 450	6 739

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	12 305	12 305	86
Unknown	0	0	0	7 039	75
Total	0	0	12 305	19 344	85

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	12 305	12 305	86
Unknown	0	0	0	7 039	75
Total	0	0	12 305	19 344	85

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	0	7 039
Calcrete	0	0	12 305	12 305
Total	0	0	12 305	19 344

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	19 000

Mexico

Uranium exploration and mine development

Historical review

Uranium exploration began in 1957, using both ground and aerial prospecting with geological and radiometric methods. Limited technical and financial resources initially hampered national exploration efforts, but these problems were alleviated by government support, particularly from 1972 to 1980.

Until 1979, exploration was performed by the National Institute of Nuclear Energy. In 1979, the responsibility for exploration was vested in Uranio Mexicano (URAMEX). The areas explored, in order of importance, were in the states of Chihuahua, Nuevo León, Tamaulipas, Coahuila, Zacatecas, Queretaro and Puebla. Uranium exploration was stopped in May 1983 and URAMEX was dissolved in February 1985.

In 2009, the Mexican Geological Survey reactivated radioactive exploration in Mexico, to validate and re-evaluate the resources reported by URAMEX according to international standards. This involves the analysis of the preliminary information available, as well as complementary studies of geology, geochemistry, geophysics and drilling, simultaneously exploring new locations with uranium potential.

In order to gain a better knowledge of the uranium resources located in Peña Blanca (Chihuahua State), Los Amoles (Sonora State) and La Coma area (Nuevo León State), exploration and assessment works were continued through drilling programmes. During the period 2013-2016, a total of 16 442 metres were drilled in 144 holes.

Recent and ongoing uranium exploration and mine development activities

In the 2019-2021 period, exploration activities slowed down from previous years, with no drilling campaigns carried out.

During 2017-2018, a total of 5 164 metres were drilled in 47 holes with core recovery at Peña Blanca, Los Amoles and La Coma sites.

Other areas under study were Buenavista, Chapote, La Diana, Peñoles, La Presita, Trancas, Dos Estados and Santa Fe in Nuevo León State using geological and radiometric prospecting methods, which was done to develop a base map URAMEX drill holes made in the 1980s, and to assess the uranium mineralisation and geometry of the ore bodies.

In Durango State, the main exploration activities have focused on Santiago Papasquiaro, where anomalies and evidence of surface and underground uranium minerals were defined.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Past evaluation of these projects by URAMEX did not fulfil the international standards of evaluation. Potential was demonstrated, however, and the Mexican Geological Survey began a programme to evaluate resources following international standards. The first results of this programme were presented in the Red Book 2020, and there are no changes regarding identified conventional resources reported in this edition.

Projects	Tonnes U (in situ)
Las Margaritas, Chihuahua State	597
El Puerto III, Chihuahua State	180
El Nopal I, Chihuahua State	422
Los Amoles, Sonora State	399
La Coma, Nuevo León State	852
Buenavista, Nuevo León State	1 455
El Chapote, Nuevo León State	1 104
La Diana, Nuevo León State	940
Peñoles, Nuevo León State	191
La Presita, Nuevo León State	185
Trancas, Nuevo León State	130
Dos Estados, Nuevo León State	169
Santa Fe, Nuevo León State	90

Undiscovered conventional resources (prognosticated and speculative resources)

There are 53 uranium occurrences in Mexico that will be evaluated by the Mexican Geological Survey.

Unconventional resources and other materials

The San Juan de la Costa phosphorite deposit is estimated to contain significant uranium resources.

Uranium production

Historical review

From 1969 to 1971, the Mining Development Commission operated a plant in Villa Aldama, Chihuahua State. The facility recovered molybdenum and by-product uranium from ores mined in the Sierra de Gomez, Domitilia (Peña Blanca) deposits and other occurrences. A total of 49 tU was produced. At present, there are no plans for additional uranium production.

Uranium requirements

As of 1 January 2021, two boiling water reactors with a total net installed capacity of 1.4 GW were in operation at the Laguna Verde Nuclear Power Plant. These two units have been in operation since 1990 and 1995, respectively, together supplying about 4-5% of the country's electricity.

In 2015, an application for a licence renewal of both Laguna Verde units was submitted to the Mexican regulatory authority to allow their operation for an additional 30 years.

In 2020, Mexico's Secretariat of Energy (SENER) authorised the renewal of the operating licence for unit 1 of the Laguna Verde Nuclear Power Plant for an additional 30 years to 2050. The existing licence for unit 2 expires in May 2025.

Supply and procurement strategy

An open bid system for uranium purchases is under study for three reloads (2022-2025).

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The 1984 Act on Nuclear activities, adopted pursuant to Article 27 of the Constitution, entered in force on 5 February 1985. It specifies that the exploration, exploitation, and the benefit of radioactive minerals are the exclusive domain of the government of Mexico. Exploration activities are exclusively delegated to the Mexican Geological Survey.

Uranium stocks

Uranium stocks are maintained at minimum levels to reduce costs.

Uranium exploration and development expenditures and drilling effort – domestic

(USD)

	2018	2019	2020	2021 (expected)
Government exploration expenditures	1 203 590	NA	NA	NA
Total expenditures	1 203 590	NA	NA	NA

Reasonably assured conventional resources by production and processing method

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Other or unspecified	0	0	2 450	2 450
Total	0	0	2 450	2 450

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	852	852
Volcanic-related	0	0	1 598	1 598
Total	0	0	2 450	2 450

Inferred conventional resources by production and processing method

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Other or unspecified	0	0	2 450	4 264
Total	0	0	2 450	4 264

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	2 450	4 264
Total	0	0	2 450	4 264

Net nuclear electricity generation*

	2019	2020
Nuclear electricity generated (TWh net)	10.9	11.2

* Data based on NEA *Nuclear Energy Data* reports.

Installed nuclear generating capacity to 2040*

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
1 552	1 552	1 552	1 608	1 552	3 108	1 552	3 108	1 552	3 108

* Data based on NEA *Nuclear Energy Data* reports.

Annual reactor-related uranium requirements* to 2040 (excluding MOX)**

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
392	430	532	NA	282	NA	555	NA	282	NA

* Refers to natural uranium acquisitions, not necessarily consumption during the calendar year.

** Data based on NEA Nuclear Energy Data reports.

Mongolia

Uranium exploration and mine development

Historical review

The history of uranium exploration in Mongolia can be divided into three phases. The first phase started immediately after World War II, with investigations directed at the search for uranium contained in other, non-uranium deposits. During the period 1945-1960, numerous uranium occurrences were discovered in the brown coal deposits of eastern Mongolia.

The second phase of exploration covered the period between 1970 and 1990. Under a bilateral agreement between Mongolia and the former Soviet Union, specialised geological surveys were conducted by the Geological Reconnaissance Expedition of the Soviet Ministry of Geology with a result of 1 600 radioactive anomalies and hundreds of radioactive occurrences identified by the joint expedition. Full airborne gamma-ray spectrometric surveys at a scale of 1:25 000 and 1:50 000 were conducted over 420 000 km^2, covering about 27% of Mongolian territory; at a scale of 1:200 000 over 450 000 km^2, covering about 28% of the territory; and at a scale of 1:1 000 000 over 224 000 km^2 in the Altai, Khangai mountains and Gobi Desert, covering about 14% of the Mongolian territory. The territory along the border with the People's Republic of China and the central Mongolian mountain area, about 30% of the country, was not included in these surveys.

Metallogenic investigations at the scale of 1:500 000 over a 500 000 km^2 area, and more detailed geological mapping and exploration at the scale of 1:200 000-1:50 000 over 50 000 km^2 of territory in Mongolia, were also completed. This work included 2 684 000 m of surface drilling, 3 179 000 m^3 of surface trenching, and 20 800 m of underground exploration.

The third phase of exploration started in the 1990s with private stakeholder engagements including local and foreign entities. As a result of the depressed uranium market, exploration strategies changed globally towards the exploration for low-cost uranium deposits, especially sandstone-type deposits. Uranium exploration was focused on Mesozoic and Cenozoic basins in southeast Mongolia. The "uranium" state-owned manufacturing enterprise, in co-operation with the International Atomic Energy Agency (IAEA), assessed the uranium potential of Mongolia in two phases between 1993 and 2001. The studies that were completed focused on identifying the potential for uranium mineralisation in sedimentary and metasomatised settings.

Based on these surveys, the territory of Mongolia was classified into four uranium-bearing metallogenic provinces: Mongol-Priargun, Gobi-Tamsag, Khentei-Daur and Northern Mongolia. Each of these provinces has a different geology and hosts different deposit types. Mineral associations and ages of mineralisation also vary. Within these provinces, 13 uranium deposits, about 100 uranium occurrences and 1 400 showings and radioactive anomalies were identified.

The Mongol-Priargun metallogenic province is located in eastern Mongolia, coinciding with a 70 to 250 km wide continental volcanic belt that can be traced over some 1 200 km, from the Mongolian Altai to the Lower-Priargun region. This territory includes deposits and occurrences with fluorite-molybdenum-uranium associations resulting from volcano-tectonic events. Distinct uranium mineralisation districts of the Northern Choibalsan, Berkh, eastern and central Gobi are included in this area. The Dornod ore field of Northern Choibalsan includes the uranium deposits of Dornod, Gurvanbulag, Mardaingol, Nemer and Ulaan, as well as other polymetallic and fluorite associations. The Choir and Gurvansaikhan Basins of the eastern and central Gobi uranium mineralisation district include the Kharaat and Khairkhan uranium deposits, among others.

The Gobi-Tamsag metallogenic province covers a territory 1 400 km long by 60 to 180 km wide in southern Mongolia. It is characterised by numerous uranium occurrences in terrigenous sediments. The district includes a prospective uranium deposit in the south, near the Dulaanuul and Nars deposits, and numerous other occurrences, as well as other prospective uranium-bearing sedimentary basins, such as the Tamsag, Sainshand and Zuunbayan Basins, among others.

The Henter-Daur metallogenic province (700 km long by 250 km wide) includes the Khangai and Khentii mountains. In this area, uranium occurrences in granite can be found, such as the Janchivlan ore field, which shows some promise of becoming a deposit of economic interest.

The Northern Mongolian metallogenic province is the largest (1 500 km long by 450 km wide) of the four metallogenic provinces. The north-western part of Mongolia is characterised by a variety of minerals such as uranium, thorium, and rare earth elements related to alkaline mineralisation, and uranium and thorium in metasomatites, pegmatite, magmatic, and quartz schist host rocks.

Recent and ongoing uranium exploration and mine development activities

There are two types of uranium exploration activities in Mongolia: prospecting aimed at the discovery of new deposits and the exploration of previously discovered deposits to increase resource endowments.

Four companies are carrying out exploration activities in Mongolia. From 2019 to 2020, the majority of uranium prospecting was performed in the south Mongolian sedimentary basins to identify sandstone-type uranium mineralisation that is amenable to in situ leaching (ISL) mining.

Badrakh Energy conducted major exploration and development activities during 2019-2020 at the Zuuvch Ovoo and Dulaan Uul uranium deposits in Dornogobi province in south-eastern Mongolia. As a result, uranium resources of the Zuuvch Ovoo deposit were increased to 93 291 tU and a technical report was submitted to the Mongolian Professional Committee of Resources in February 2020. The deposit will be mined by ISL using sulphuric acid. The test mining will be conducted on 2 hexagonal cells located 470 m from each other, each of which will consist of 6 injection wells and one production well. Fifteen groundwater monitoring wells were drilled and equipped outside and inside of each cell and at different aquifer horizons along the direction of groundwater flow. In 2021, after receipt of all required authorisations from Mongolian governmental authorities, including the validation of a Detailed Environmental Impact Assessment and Environmental Management Plan 2021, Badrakh Energy started the ISL pilot test at the North ISL cell. On 10 August 2021, the pilot test successfully produced its first kilogram of uranium concentrate. Operations of the North ISL cell continued for about 200 days until the end of January 2022 to provide information confirming key technical and economical parameters for future industrial production. Cell #2 is expected to start mining when mining from Cell #1 is completed.

There are currently eight deposits on which mining feasibility studies have been completed and approved by the Mongolian Professional Committee of Resources.

Uranium exploration expenditures amounted to MNT 418.7 million (Mongolian tugrug) in 2019, MNT 197.2 million in 2020, and MNT 209.4 million in 2021. No exploration drilling was completed in 2020, compared with 1 100 m reported in 2019.

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2021, Mongolia's total identified conventional recoverable resources amounted to 144 620 tU, while in situ resources comprised 192 241 tU. Recoverable conventional resources include 66 234 tU of reasonably assured resources (RAR) and 78 386 tU in the inferred category. All resources are recoverable at <USD 130/kgU, and 16 884 tU are recoverable at a cost of <USD 80/kgU by the acid ISL method.

Undiscovered conventional resources (prognosticated and speculative resources)

As of 1 January 2021, prognosticated resources amount to 13 300 tU, and speculative resources totalled 1 319 000 tU.

Unconventional resources and other materials

No unconventional resources have been identified.

Uranium production

Historical review

Uranium production in Mongolia started with the operation of the Dornod open-pit mine in the Mardai-gol district in 1989, based on the known uranium resources at the Dornod and Gurvanbulag deposits. With an ore grade of 0.12% U, mining production was 2 400 tU/year. Mongolia has no processing facilities. The ores mined in the Mardai-gol district were transported 484 km by rail to the Priargunsky mining and processing facility in Krasnokamensk, Russia, for processing. Because of political and economic changes in Mongolia and neighbouring areas of Russia, uranium production at Erdes was terminated in 1995.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #2				Centre #3	
Name of production centre	Emeelt mines	Gurvansaihan				Badrakh energy	
Production centre classification	Planned	Planned				Planned	
Date of first production (year)	NA	NA				NA	
Source of ore:							
Deposit name(s)	Gurvanbulag	Kharaat	Khairkhan	Gurvansaikhan	Ulziit	Dulaan uul	Zuuvch ovoo
Deposit type(s)	Volcanic	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
In situ resources (tU)	13 058	7 288	8 407	4 250	3 076	11 896	93 291
Grade (% U)	0.152	0.026	0.071	0.034	0.036	0.022	0.022
Mining operation:							
Type (OP/UG/ISL)	UG	ISL	ISL	ISL	ISL	ISL	ISL
Size (tonnes ore/day)	NA	NA	NA	NA	NA	NA	NA
Average mining recovery (%)	NA	NA	NA	NA	NA	NA	NA
Processing plan							
Acid/alkaline	Acid	Acid	Acid	Acid	Acid	Acid	Acid
Type (IX/SX)	IX	IX	IX	IX	IX	IX	IX
Size (tonnes ore/day)	NA	NA	NA	NA	NA	NA	NA
Average process recovery (%)	NA	NA	NA	NA	NA	NA	NA
Nominal production capacity (tU/year)	NA	NA	NA	NA	NA	NA	NA
Plans for expansion	No	No	No	No	No	No	No

Status of production facilities, production capability, recent and ongoing activities and other issues

Currently, no uranium is being produced in Mongolia. However, several mines are in the planning stage of development

Secondary sources of uranium

Production and/or use of mixed oxide fuels

Mongolia has not produced or used mixed oxide fuels.

Production and/or use of re-enriched tails

Mongolia currently does not have a uranium enrichment industry. Re-enriched tails are not used or produced.

Production and/or use of reprocessed uranium

There is no production or use of reprocessed uranium.

Status of production facilities, production capability, recent and ongoing activities and other issues (including information on uranium recovery methods)

Currently, no uranium is being produced in Mongolia.

Ownership structure of the uranium industry

The Nuclear Energy Law of Mongolia defines the ownership of radioactive minerals and state participation in the exploitation of radioactive minerals. Article 5 states that:

5.1: Radioactive minerals occurring in the subsoil of Mongolia shall be the property of the state.

5.2: Provided that the radioactive mineral deposit, for which exploration and reserves determination was conducted by state budget financing, and is jointly exploited with others, the state shall directly possess free of charge no less than 51% of shares of the company that will be set up jointly.

5.3: The state shall directly possess free of charge no less than 34% of shares of the company holding a special licence for exploitation of the radioactive mineral deposit, for which exploration and reserves determination were conducted without state budget involvement and was recorded in the state integrated register.

5.4: Provided the state owns shares exceeding the percentages specified in the clauses 5.2 and 5.3 of this law, the State Great Khural shall fix this share by presentation of the government in view of the size of investment made or to be made by the state.

National policies relating to uranium

The Mongolian government considers the mining of uranium deposits an important national interest as it can positively influence and improve the national economy. As a result, the government has developed a special programme on uranium and is committed to implementing it.

The programme covers the following policies and guidelines:

- Geological exploration and mining of uranium deposits, processing, and marketing of uranium ores in Mongolia. The purpose is to reduce Mongolian government investment and to encourage foreign investment.
- Developing intensive and effective co-operation with international organisations involved in the prospecting, mining, and sale of uranium and other raw materials for nuclear energy.
- Developing all of the necessary regulations, instructions and recommendations for activities related to uranium mining.
- Studying possibilities of recovering uranium from phosphate and brown coal deposits and developing alternative extraction techniques.
- Training national personnel for uranium studies and production and introducing advanced technology, instruments, and tools of high precision.
- Setting up a government enterprise responsible for monitoring and co-ordinating uranium exploration and production, as well as developing and implementing government policy and strategies in the field of uranium exploration based on mobilising efforts of national uranium specialists.

Uranium exploration and development expenditures and drilling effort – domestic

(Mongolia tugrug millions)

	2019	2020	2021 (expected)
Industry* exploration expenditures	418.7	197.2	209.4
Government development expenditures	0	0	0
Total expenditures	418.7	197.2	209.4
Industry* exploration drilling (m)	1 100	0	0
Subtotal exploration drilling (m)	1 100	0	0
Total drilling (m)	1 100	0	0

* Non-government.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	20 744	20 744	75
Open-pit mining (OP)	0	0	1 762	1 762	80
In situ leaching acid	0	7 572	43 728	43 728	75
Total	0	7 572	66 234	66 234	

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	20 744	20 744	75
Conventional from OP	0	0	1 762	1 762	80
In situ leaching acid	0	7 572	43 728	43 728	75
Total	0	7 572	66 234	66 234	

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	7 572	43 728	43 728
Volcanic-related	0	0	22 506	22 506
Total	0	7 572	66 234	66 234

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	15 582	15 582	75
Open-pit mining (OP)	0	0	5 263	5 263	80
In situ leaching acid	0	9 311	57 541	57 541	75
Total	0	9 311	78 386	78 386	

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	15 582	15 582	75
Conventional from OP	0	0	5 263	5 263	80
In situ leaching acid	0	9 311	57 541	57 541	75
Total	0	9 311	78 386	78 386	

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	9 311	57 541	57 541
Volcanic-related	0	0	20 845	20 845
Total	0	9 311	78 386	78 386

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
13 300	13 300	13 300

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
1 319 000	1 319 000	NA

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021(expected)
Open-pit mining	535	0	0	535	0
Total	535	0	0	535	0

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Volcanic-related	535	0	0	535	0
Total	535	0	0	535	0

Short-term production capability

(tonnes U/year)

2025				2030			
A-I	A-I	B-I	A-II	B-II	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA
2035				**2040**			
A-I	A-I	B-I	A-II	B-II	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA

Namibia

Uranium exploration and mine development

Historical review

Uranium was first discovered in the Namib Desert in 1928 in the vicinity of the Rössing Mountains, but it was not until the late 1950s that the Anglo American Corporation of South Africa prospected the area through drilling and limited underground exploration. As a result of erratic uranium prices, lack of demand, and limited economic prospects for uranium at that time, Anglo American abandoned its work.

With the upswing in the uranium market demand and prices, extensive uranium exploration started in Namibia in the late 1960s. Several airborne radiometric surveys were conducted, and numerous anomalies were identified. In 1966, after discovering uranium occurrences, Rio Tinto acquired the rights to the low-grade Rössing deposit, located 65 km inland from the town of Swakopmund on the Atlantic coast. Trekkopje, a near-surface calcrete deposit just north of Rössing and Langer Heinrich, another calcrete deposit situated 50 km southeast of Rössing, were also discovered during this period.

Mining commenced in 1976 at Rössing and exploration intensified as uranium prices increased sharply. However, in the early 1980s, the sharp decline in uranium prices caused a rapid curtailment of exploration and mine development efforts. This was untimely as refined and proven exploration techniques appeared poised to discover new deposits.

Beginning in 2003, rising uranium prices once again stimulated extensive exploration activity, mainly in the Namib Desert. Based on earlier successes, two major types of deposits were targeted: intrusive-type associated with alaskite, as at Rössing, and surficial calcrete-type deposits, as at Langer Heinrich.

In 2002, Paladin Energy bought the Langer Heinrich tenement. The Langer Heinrich surficial, calcrete-hosted uranium deposit is in the Namib Naukluft National Park (NNNP), approximately 85 km east northeast of the major Walvis Bay seaport. The ore occurs over 15 km in a paleochannel system approximately 50 m deep, and an exploration prospecting licence covers the western extension of the mineralised Langer Heinrich paleochannel. In 2015, this prospecting licence was converted to a mining licence. Originally identified in situ resources amounted to 49 179 tU at an average grade of 0.040% U.

Construction at the Langer Heinrich project commenced in September 2005 and staged commissioning of the plant began in August 2006. Mining commenced in 2007 with a proposed 25-year life. Due to sustained low uranium prices, Langer Heinrich was placed in care and maintenance in August 2018. The mine is expected to remain in care and maintenance until the uranium spot price makes it economical to restart the facility on a sustainable basis.

In 2005 French state-owned Orano (at that time Areva) purchased Trekkopje from the Canadian company UraMin and began construction of an alkaline heap leach mine in 2008, as well as an associated seawater desalination plant. The Trekkopje Project, located approximately 65 km northeast of the coastal town of Swakopmund, embodies the Klein Trekkopje and Trekkopje surficial uranium deposits, with 80% of the mineralisation contained in the top 15 m of strata below the surface. Hosted in calcium carbonate cemented (calcrete) conglomerates of Cenozoic age, the basal channels in the Trekkopje area follow the northeast trending structural grain of the underlying basement rocks. The mine was developed in a staged process, with Phase 1 (“Mini”), designed to validate the chemistry of the heap leach process successfully completed in 2009. Phase 2 (“Midi”) treated 3 million tons of ore to prove the commercial process before scaling up to full production. Phase 3 ("Maxi") represented the full production stage of the mine, which was expected to produce about 3 000 tU per annum. However, due to the depressed uranium market, the mine was put on care and maintenance at the end of 2012. As of 1 January 2013, known resources for Klein Trekkopje and Trekkopje amounted to over 45 000 tU at 0.013% U.

Other uranium projects that were issued mining licences at the time but have not commenced construction are the Norasa (original name Valencia) and the Zhonge Projects.

Discovery holes for the Husab (initially known as Rössing South) uranium deposit were drilled in late 2007 and chemical assay results were released in February 2008. Swakop Uranium had in total completed over 800 000 m of combined reverse circulation and diamond core drilling since the drilling programme began in 2006. In 2008, Extract Resources discovered the Husab uranium deposit.

Exploration efforts continued, but low uranium prices since 2011, partly because of the Fukushima Daiichi accident, slowed activity. Nonetheless, substantial growth in uranium exploration took place in the Erongo area of west-central Namibia, focused mainly on previously known deposits with considerable historical data. For example, Bannerman Mining Resources Pty Ltd progressed the Etango Project from an initial scoping study (2007) and pre-feasibility study (2009) to a definitive feasibility study in 2012. It then built a heap leach demonstration plant in 2015 to test the proposed metallurgical process. In total, over 300 000 m of exploration drilling has been completed in the Etango Project area.

For the Rössing mine, a positive evaluation of extending the mine life led to the expansion of the existing pit to expose more of the steeply dipping ore body known as SJ. Between 2007 and 2010, exploration was focused on extensions of the main SJ ore body, as well as the adjacent SK and SH ore bodies. However, the SK body contains largely refractory mineralisation (betafite) for which the existing process plant is not suited. Since 2010, the main exploration focus has been on the southernmost Z20 deposit that extends across the lease boundary into the adjacent lease held by Husab. A total of 24 000 m of drilling was completed on Z20 to determine inferred resources by the end of 2012, and a third phase of drilling on the Z20 ore body was completed during 2013. Data indicated in situ resources of over 46 000 tU at higher grades (0.023% U) than in the main orebody.

Other uranium exploration companies that continued work include Marenica Energy (currently known as Elevate Uranium Ltd) and Reptile Mineral Resources and Exploration (Pty) Ltd (RMR). RMR is a wholly owned Namibian registered subsidiary of the Australian public company Deep Yellow Limited (DYL). Active in Namibia since 2006, RMR holds three exclusive prospecting licences including the Omahola, Tubas, Tumas and Aussinanis deposits, which are situated in the NNNP. Deposits are hosted in alaskite granites and in surficial paleochannel calcrete and sand sediments. The Tumas palaeochannel system extends over more than 100 km. It contains secondary uranium mineralisation (carnotite) in fluviatile grits, calcrete and gravel sequences in a complex palaeochannel system. The Tubas Sand Project consists primarily of low-grade secondary uranium mineralisation (carnotite) in well-sorted aeolian sediments. The Aussinanis deposit (MDRL3498) forms a shallower palaeochannel system, also with carnotite rich calcrete. RMR is also the manager of the Nova Joint Venture (NJV), which includes Tumas North and Chungochoab deposits. All tenements are situated in the NNNP.

Metals Australia Ltd owns 100% of the Mile 72 uranium project, located near Henties Bay on the west coast of Namibia. The project is considered prospective for calcrete and gypcrete hosted uranium mineralisation as well as alaskite hosted uranium. A high-resolution airborne geophysical survey, radon cup, surface trenching and drilling exploration activities have been conducted. Activity during 2015 and 2016 was restricted to geological and economic assessments.

Over 60 exploration licences were issued until early 2007, when the Namibian government imposed a moratorium on new licences pending the development of new policies and legislation, primarily in response to concerns about the water and energy requirements of uranium mining.

Recent and ongoing uranium exploration and mine development activities

In January 2017, the Namibian government lifted the 10-year moratorium on new applications for exploration licences for nuclear fuel minerals, and since then, 52 new licences have been granted as of the end of 2019.

Rössing

A revision of the pricing outlook resulted in the removal of the Z20 and Phase 4 mineralised zone from the 2018 JORC compliant resource declaration. This decision was taken as a result of a financial analysis, which demonstrated that with the revised downward pricing outlook, the Z20 deposit would not contribute any additional value to the existing SJ Pit operations. However, the resources contained within the Phase 4 pushback, as well as the inferred resources within the Phase 2 and 3 pushbacks, continue to demonstrate value.

Langer Heinrich

There has been no recent exploration activity due to continued low uranium prices. Paladin released the Mine Restart Plan in June 2020, setting a pathway to transition back into reliable production, with targeted investment to maximise plant reliability and runtime. During 2020 the Langer Heinrich Mine activities continued under a care and maintenance plan. There were no production or development activities during this period. The mine is expected to remain in care and maintenance until the uranium spot price makes it economical to restart the facility on a sustainable basis.

Trekkopje

The operation is in care and maintenance status, during which time Orano has conducted research to improve uranium recovery. An optimised process was developed that enhances permeability in the heap by adding cement at the agglomeration stage and recovery of a substantial part of the reagents used is accomplished through membrane technology. The desalination plant built in association with the mine continued to supply sufficient water to meet the demand of other uranium mines and other users in the coastal area. Production capacity was boosted to 1 million m^3/month to meet increased demand when the Husab mine began production.

Husab

The main part of the Husab orebody lies approximately 5 km south of the Rössing mine. The 8-km long uranium deposit lies under a cover of shallow alluvial sand. Estimated in situ identified resources for all deposits currently licensed to Swakop Uranium (Husab and Ida Dome deposits) amount to 234 000 tU grading at about 0.03% U, 136 000 tU of which in the RAR category.

Etango

Bannerman Resources' Etango Project consists of three prospects: Anomaly A, Oshiveli and Onkelo. These prospects contain uraniferous sheeted leucogranite alaskites bodies, very similar to those at Rössing. Although extensions continue to 400 m below the surface, two-thirds of the resource base is located less than 200 m below the surface. Bannerman is also investigating potential satellite pit opportunities at Ondjamba and Hyena deposits. Total identified in situ uranium resources amount to about 82 400 tU, including 57 850 tU RAR.

Reptile Mineral Resources (RMR) Projects

Total identified in situ resources amount to 75 353 tU: 17 348 tU of which occur at the Omahola Project, including the Ongolo and MS7 alaskite as well as the Inca skarn deposits, and 58 005 tU are contained in the Tumas, Tubas and Aussinanis surficial calcrete deposits.

Tumas Project: work continued expanding the calcrete associated uranium mineralisation in Tumas 1, 2 and 3 and Tubas zones, collectively referred to as the Tumas Project. Between 2017 and 2020, work focused on advancing the Tumas and Tubas projects by expanding the calcrete associated uranium resources at the Tumas 1 East, 1, 2 and 3 deposits, as well as at the

Tubas Red Sand and Calcrete deposits. A total of 1 663 reverse circulation (RC) holes amounting to more than 30 000 m were drilled between 2019 and May 2021. Drilling work aimed at extending the mineral resources and converting them to a higher confidence level. These deposits collectively contain 51 080 tU grading approximately 0.020% U. In addition, 30 diamond cored holes totalling 602 m were drilled to collect sample material for metallurgical test-work.

Between 2019 and 2021 the focus was to advance the Tumas Project by conducting a scoping study that directly led into a pre-feasibility study (PFS). The PFS was completed with positive results in February 2021. It confirmed the technical and economic viability of the project, delivering the following key outcomes:

- Utilises only 50% of the total available mineral resources.
- Inferred resources converted to indicated resources at a rate of 95%.
- Established a maiden ore reserve at a 63% conversion rate from indicated resources to probable reserves.
- Confirmed or improved of the Tumas scoping study assumptions.

On the back of the PFS results, the decision was made to immediately proceed with a definitive feasibility study (DFS), with a key focus on enhancing and further optimising the development option recommended in the PFS. A drilling programme is underway to define sufficient indicated and measured resources outlined as being required by the PFS. The DFS is expected to be completed towards end of 2022. RMR has commenced an environmental impact assessment (EIA) and is preparing for a mining lease application (MLA).

Aussinanis Project: Contains approximately 7 000 tU of indicated and inferred in situ resources grading at about 0.02% U. Due to the depressed uranium market and the fact that EPL3498 is considered fully explored, an application was made in May 2017 for a Mineral Deposit Retention License (MDRL) and the Ministry of Mines and Energy (MME) granted the application in January 2020.

RMR is also manager of the Nova JV, which is exploring two greenfield exclusive prospecting licences (EPLs) in the NNNP. Exploration undertaken between 2017 and 2020 identified several uranium prospects, but in situ resources are yet to be identified. The most prospective target is Barking Gecko (EPL3669), where uranium mineralisation is hosted by alaskitic dykes. In 2020 drilling delineated two prospective zones, namely Barking Gecko North and Barking Gecko South.

Marenica

Elevate Uranium Ltd (formerly Marenica Energy) has a 75% interest in the project, while the other partners are Xanthos Mining Limited (20%) and Millennium Minerals (5%). The Marenica Project includes the calcrete-hosted uranium deposits of Marenica and MA7 located in the same palaeochannel system that hosts Orano's Trekkopje uranium deposit, which has similar mineralogical characteristics to Marenica. The Marenica Project has identified mineral resources of 23 579 tU (61.3Mlb U_3O_8) at 0.008% U (93 ppm U_3O_8).

During 2015 and 2016, the company suspended all drilling activities due to depressed market conditions and focused on metallurgical testing of so-called "U-pgrade" beneficiation processes to increase the grade of mined ore prior to leaching. Feed grade can be elevated by over 50 times to ~5 000 ppm U_3O_8 (~ 4 200 ppm U). Calcite rejection has also enabled the proposed leach circuit to be changed from an alkali leach (with higher operating temperatures and slower kinetics) to acid (at ambient temperature and rapid kinetics), thereby reducing expected capital expenses and operating costs.

In mid-2020, Elevate Uranium announced a new uranium discovery at EPL 7278 ("Hirabeb"). Exploration on the tenement identified a massive palaeochannel system that extends over 36 kilometres. The primary palaeochannel is mineralised over most of its length with the potential to host a significant uranium deposit. An airborne electromagnetic survey, flown in April 2021, covered the Hirabeb tenement and is expected to expand on the palaeochannel system. Furthermore, Elevate announced the discovery of a new palaeochannel system at EPL 7662 (Namib IV) that is 19 km long and as wide as 6 km.

Happy Valley

Located approximately 110 km northeast of Swakopmund and east of Rössing, the Happy Valley Project area was granted to Zhonghe Resources on 1 August 2006. Zhonghe is a Namibian registered company founded in 2008 by the China National Uranium Corporation (CNUC; 58%), a wholly owned subsidiary of the CNNC, and co-owned by two private companies, China Mineral Resources Investment and Development P/L Nam-China (21%), and Springbok Investment Ltd (21%).

Exploration work was started in the area in 2007 and JORC compliant in situ resources amounting to 40 730 tU at 0.016% U were defined. A feasibility study was undertaken from 2013 to 2018 while Zhonge Resources continued to focus on resource evaluation and economic reassessment. Since CNUC has taken over Rössing Uranium Limited, the Zhonge Resources project could serve as a backup resource for Rössing Uranium Ltd.

Engo Valley

The Engo Valley Project consists of a series of uranium anomalies exposed in and adjacent to Karoo sedimentary rocks. The project is located 600 km north of Swakopmund, on the Skeleton Coast of northern Namibia. The licence was relinquished in 2014 following a review of the project considering its remote location.

*Wings**

In south-eastern Namibia, Russian-owned Uranium One, through its Namibian daughter company Headspring Investments Pty., conducted ground geophysical and geochemical surveys during 2016-2017, completed metallurgical test studies of core with uranium mineralisation in 2018, and began systematic intensive exploration drilling in 2019. Exploration drilling volumes increased from 9 430 m in 2019 to 34 818 m in 2020. As a result of 2019-2020 activities, a new sandstone-type uranium deposit was discovered with resources confirmed by a JORC compliant technical report amounting to: indicated (RAR) resources worth 14 700 tU, inferred resources worth 9 900 tU and exploration potential of 40 000 tU. Based on 2020 exploration and hydrogeological test results, resources are potentially amenable for development by ISL. A PFS completed in 2021 has confirmed positive economics for the ISL mining method with all in production cash cost of USD 54.2/kgU. The 2021 exploration programme included a further 42 440 m of drilling aimed at the identification of additional resources and preparation for an ISL pilot test. This is the first time that sandstone-type mineralisation potentially amenable for ISL recovery has been discovered in Namibia.

Identified conventional resources (reasonably assured and inferred resources)

Total identified in situ conventional resources in Namibia amounted to 636 916 tU as of 1 January 2021. Recoverable known resources amounted to 509 532 tU, including 322 822 tU in the reasonably assured and 186 711 tU in the inferred resource categories. The average overall recovery factor for all mining and processing methods is 80%. Deposits in Namibia are typically large and low grade. About 92% of the recoverable identified uranium resources are classified in the <USD 130/kgU cost category, with the remainder reported in the <USD 130 and <USD 260/kgU categories. For the first time, Namibia has reported recoverable resources in the <USD 80 kg/U category, amounting to 19 680 tU that belong to the Wings sandstone-type deposit potentially amenable for ISL mining.

Compared with data as of 1 January 2019, there has been an increase of 5 308 tU in total recoverable and 6 636 tU in in situ resources. This is the result of additional resources identified at Tumas and Wings and decreases due to 2019 and 2020 mining depletion at the Husab and Rössing mines, along with re-estimation of historical resources at Trekkopje.

* Information provided by Russia.

Undiscovered conventional resources (prognosticated and speculative resources)

Undiscovered resources are estimated in areas adjacent to deposits with identified resources in Happy Valley, Etango, Tumas, Husab and Wings. As of 1 January 2021, prognosticated resources amounted to 57 000 tU and speculative resources totalled 150 700 tU.

Uranium production

Historical review

Rössing Uranium Limited was formed in 1970 to develop the Rössing deposit. Rio Tinto was the leading shareholder with 51.3% of the equity when the company was formed. Rio Tinto subsequently increased its stake to 69% of the project. Mine development commenced in 1974 and initial production began in July 1976, but full design capacity of 3 845 tU/y was not achieved because of the highly abrasive nature of the ore, an aspect not identified during the pilot plant testing stage. The production target was eventually reached in 1979 after plant design changes were implemented. From the date of first production in July 1976 to the end of 2020, a cumulative total of over 120 000 tU had been produced at Rössing. In 2019, Rio Tinto plc sold its 69% share in Rössing to CNUC, a wholly owned subsidiary of government-owned CNNC. CNNC is a significant player throughout the entire nuclear fuel cycle and it plans to keep the Rössing operation in production.

Paladin Energy Ltd. (currently Paladin) acquired Langer Heinrich project (LHU) from Aztec Resources Ltd (formerly Acclaim Uranium NL) in August 2002. In July 2014, Paladin Energy sold a 25% interest in the mine to CNNC Overseas Uranium Holding Limited, a wholly owned subsidiary of CNNC. Construction of the Langer Heinrich project commenced in September 2005 and staged commissioning of the plant began in August 2006. Mining commenced in 2007 with a proposed 25-year life to 2030. The initial planned production level of 1 040 tU/yr was achieved in 2008. This was followed by the Stage 2 expansion to 1 350 tU/yr in 2010. Stage 3 expansion to 2 030 tU/yr was completed in 2012. A Stage 4 expansion feasibility study and an environmental impact assessment were submitted to the government, but subsequently the project was put on hold. Due to sustained low uranium prices, the Langer Heinrich Mine (LHM) was placed in care and maintenance in August 2018.

Swakop Uranium developed and constructed the Husab mine, situated approximately 5 km south of the Rössing mine and 45 km northeast of Walvis Bay port. The project received environmental clearance in January 2011 and a mining licence later that same year. An environmental clearance certificate was awarded in December 2011. Construction commenced in October 2012 and the first uranium oxide was drummed in December 2016. Construction of Husab created more than 6 000 temporary jobs. Until April 2012, Swakop Uranium was a fully owned subsidiary of Extract Resources, an Australian company listed on the Australian, Canadian and Namibian stock exchanges. In March 2012, Chinese state-owned China Guandong Nuclear Power Corporation (CGNPC) acquired the project in a takeover bid worth USD 2.4 billion. In November 2012, Epangelo, the Namibian state-owned mining company, finalised an agreement with Swakop Uranium under which Namibian state company Epangelo obtained a 10% stake in Swakop Uranium.

Status of production facilities, production capability, recent and ongoing activities, and other issues

Total uranium production in Namibia declined from 3 246 tU in 2014 to 2 992 tU in 2015 but then rebounded to 3 593 tU in 2016. Production continued to increase to 4 221 tU in 2017 and 5 520 tU in 2018. The start-up of the Husab mine is the main reason for national production increases since 2016. In 2020, uranium production in Namibia amounted to 5 412 tU, 3 301 tU of which was produced at Husab and 2 111 tU at Rössing.

Rössing

Production at Rössing Uranium has steadily increased over the last few years as the mine has accessed higher-grade ore after the Phase 2 and 3 pushbacks: from 1 055 tU in 2015, production has increased gradually to 2 111 tU in 2020 and 5 753 tU in 2021. The higher-grade material does, however, come with increased calcium content, limiting processing plant capacity. To process the higher calcium carbonate containing ores, the processing plant's annual capacity was reduced to 9.2 million tonnes per annum. The current mine plans foresee a cessation of Rössing production at the end of 2026.

Langer Heinrich

From the date of first production in March 2007 to the end of 2018, a total of 16 449 tU was produced at the Langer Heinrich Mine (LHM). The operations at LHM were suspended in August 2018 due to sustained low uranium spot prices, and the mine was placed in care and maintenance. There have been no production or development activities since 2018. In June 2020, Paladin released the Mine Restart Plan, setting a pathway to transition back into reliable production, with targeted investment to maximise plant reliability and runtime. The mine is expected to remain in care and maintenance until the uranium spot price makes it economical to restart the facility on a sustainable basis.

Trekkopje

Following Phase 1 trial mining with 250 000 t of ore and processing operations, Phase 2 pilot tests, heap leach trials (using a sodium carbonate/bicarbonate leach process) and construction of the main production pad in 2010, a final production level of 2 545 tU/yr (3 000 t U_3O_8/yr) was envisaged. Production, which was limited to 251 tU and 186 tU in 2012 and 2013 respectively, demonstrated the feasibility of the technical process and confirmed production costs. However, as a direct consequence of low uranium prices, the project was placed in care and maintenance in mid-2013. The mine is expected to remain under care and maintenance until the uranium price makes it economical to restart production.

Husab

With a conventional, large-scale open-pit mine and a conventional agitated acid leach process plant, Husab has a nameplate capacity of 5 700 tU/yr (15 Mlbs U_3O_8/yr). Mining began in May 2015 and uranium production reached 1 140 tU in 2017, rising to 3 026 tU in 2018 and maintaining a level of 3 300 to 3 400 tU during 2019-2020. The feasibility study showed a production cost of USD 83/kgU (USD 32/lb U_3O_8), including royalties, marketing and transport, and a capital cost of USD 1.66 billion. The mining fleet is expected to move 15 million tonnes of ore per year from two separate open pits to feed a processing plant producing 5 700 tU per year. Total mining fleet design capacity for ore and waste rock transportation is 120 million tons per annum.

Future production centres

Etango

After receiving environmental approvals to proceed with development of the Etango mine, completing a scoping study in September 2007 and a preliminary feasibility study, Bannerman Resources confirmed the viability of the project with a long-term uranium price of about USD 159/kgU (USD 61/lb U_3O_8) with pre-production capital costs estimated at USD 870 million. Additional work produced a reduction in break-even costs to USD 135/kgU (USD 52/lb U_3O_8) and reduced capital costs to USD 793 million for 16 years of operation, producing 2 770 tU/y from a conventional open-pit mine. Subsequent work further reduced the pre-production capital cost estimate to USD 720 million.

Norasa

With estimated annual production of about 2 000 tU over a 15-year mine life, at costs of USD 86/kgU (USD 32.96/lb U_3O_8) over the first 5 years of production, and USD 90/kgU (34.72/lb U_3O_8)

over the mine life, the project is expected to start when uranium prices recover. Environmental approval for an open-pit mine was granted in June 2008 and a 25-year mining licence was granted in August 2008 to Valencia Uranium P/L (a wholly owned subsidiary of Forsys). In situ indicated resources of 44 200 tU and inferred resources of 6 538 tU at a cut-off grade of 0.01% U have been estimated.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5	Centre #6
Name of production centre	Rössing	Langer Heinrich	Husab	Trekkopje	Norasa	Etango
Production centre classification	Existing	Idled	Existing	Idled	Prospective	Prospective
Date of first production (year)	1976	2007	2016	2013	NA	NA
Source of ore:						
Deposit name(s)	Rössing SJ, SK,	Langer Heinrich	Husab Zones 1 and 2	Trekkopje, Klein Trekkopje	Valencia and Namibplaas	Etango
Deposit type(s)	Intrusive	Calcrete	Intrusive	Calcrete	Intrusive	Intrusive
Recoverable resources (tU)	34 134	36 874	181 455	36 445	40 590	65 416
Grade (% U)	0.025	0.045	0.033	0.012	0.017	0.016
Mining operation:						
Type (OP/UG/ISL)	OP	OP	OP	OP	OP	OP
Size (tonnes ore/day)	26 000	N/A	42 000	30 800	33 000	55 000
Average mining recovery (%)	85	N/A	88	90	77	90
Processing plant:						
Acid/alkaline	Acid	Alkaline	Acid	Alkaline	Acid	Acid
Type (IX/SX)	IX/SX	IX	IX/SX	HL/IX	IX/SX	HL/IX/NF
Size (tonnes ore/day)	26 000	N/A	40 000	100 000	30 000	55 000
Average process recovery (%)	83	88	88	80	89	87
Nominal production capacity (tU/year)	2 000	2 000	5 700	3 000	2 000	2 770
Plans for expansion (yes/no)	No	Yes	Yes	No	No	No

Employment in the uranium industry

Rössing employment has remained relatively stable from 967 employees in 2018 to 955 employees at the end of 2020 and 961 in 2021. Recruitment intensified at Husab from 2016, and in 2021, Swakop Uranium had 1 567 permanent employees and 1 250 contractors. At Langer Heinrich, the number of employees decreased from 282 in 2017 to 19 at the end of 2018, when the operation was placed in care and maintenance. The implementation of an optimised care and maintenance plan resulted in a further reduction in total employees, from 19 in 2019 to 14 in 2020.

Environmental activities and socio-cultural issues

Namibia's "Vision 2030" spells out the country's development programmes and strategies to achieve national objectives. It focuses on eight themes to realise the country's long-term vision. Uranium mine and exploration companies actively support these government objectives.

The Namibian Uranium Association

The Namibian Uranium Association (NUA) is an advocacy body for the uranium industry, assisting senior executives in shaping the context in which their industry operates. It supports policies that allow uranium to compete on its merits as a source for low-carbon energy appropriate for modern society through research, information and advocacy. Members of NUA span all Namibian uranium mining operations, most of Namibia's leading uranium exploration companies, and associated contractors.

NUA is the leading point of contact for government, media, stakeholders, and the general public interested in the position and policies of the Namibian uranium industry. NUA promotes industry adherence to sustainable development performance, product stewardship and compliance within the Namibian legislative framework. A key mission of the association's Uranium Stewardship programme is to "earn public trust for the global nuclear fuel cycle through the continued replacement of standard practice with best practice".

As part of its stewardship mission, NUA established the Namibian Uranium Institute (NUI). The NUI is guided by independent scientists who serve on its Scientific Committee. The main purpose of the NUI is to act as a communication hub for the industry in Namibia, and to promote knowledge and capacity building in specialised skills in the fields of environmental management, radiation safety and health. The NUI therefore provides an opportunity for NUA members to collectively improve safety and health performance through the identification of world-class leading practices and their implementation. As such, NUI is working closely with the Namibian government and state agencies, as well as maintaining close ties to the Namibian University of Science and Technology.

Environmental Management Act, Act No. 7 of 2007

Namibia committed itself to sound environmental management, as reflected in the Environmental Management Act, Act No. 7 of 2007 and Regulations, gazetted on 6 February 2012. The object of the act is prevention and mitigation, following environmental management principles that:

- ensure that the significant effects of activities on the environment are considered in time and with care;
- ensure that there are opportunities for timely participation of interested and affected parties through the assessment process, and that the findings of an assessment are considered before any decision is made with respect to the activities.

The Strategic Environmental Assessment and the Strategic Environmental Management Plan

The Erongo Region is characterised by aridity, vast desert landscapes, scenic beauty, high biodiversity and endemism, and heritage resources. It has the second-largest economy of all Namibian regions, and mining plays an important part. Walvis Bay and Swakopmund are among Namibia's five largest towns, but at the same time, large parts of the Erongo Region, especially along the coast, are under active conservation as national parks.

Most of the Namibian uranium exploration and mining activities occur in the Central Namib, an ecologically sensitive area containing parts of the Namib Naukluft and Dorob National Parks. Mining and associated developments are vital for Namibian economic growth, and the country strives to reconcile development objectives and mineral exploitation with environmental protection to foster long-term socio-economic growth and stability. An integrated approach is required so that development of one resource will not jeopardise the potential of another.

The need for proper environmental planning in the framework of a comprehensive environmental assessment was therefore realised at an early stage when rising uranium prices in the mid-2000s caused a uranium exploration rush. Apart from forming the Uranium Stewardship committee, a proposal was made for a strategic environmental assessment (SEA) that was subsequently carried out by the Geological Survey of Namibia. The Uranium-SEA, as it has become known, dealt with a variety of topics, such as water, energy, air quality, radiation, health, transport, tourism, biodiversity, heritage, economics, education and governance. Following an independent assessment by the International Institute for Environment and Development, a Strategic Environmental Management Plan (SEMP) was created from the SEA findings and is being implemented by the Ministry of Mines and Energy. The Namibian uranium industry has supported the SEA process and is an active partner of government in the implementation of the SEMP.

Positive impacts noted in the SEA include stimulating the Namibian economy, as well as developing skills and infrastructure. Constraints to development, such as possible water shortages, lack of skills, capacity of physical infrastructure and environmental protection, were also identified. The SEA noted that a uranium rush could impact natural physical resources, biodiversity, health, infrastructure and tourism. Good governance will be critical in minimising these impacts.

The SEMP sets out several environmental quality objectives related to socio-economic development, employment, infrastructure, water, air quality and radiation, health, tourism, ecological integrity, education, governance, heritage and future developments, closure and land use, which are to be continuously monitored as a collective proxy for measuring the degree to which uranium mine development activities are moving the Erongo Region towards a desired future state. An office has been established to administer the SEMP programme.

One of the key aspects identified in the SEMP is water. Since 2010, water has been supplied to Trekkopje from a coastal desalination plant built by Areva (now Orano) capable of supplying 20 million m^3/yr and requiring 16 MWe from the grid. Desalinated water is also supplied via the Namibian Water Corporation to Rössing, Langer Heinrich and Husab. The SEMP stated that uranium mining, mine development and exploration have not compromised community access to water supplies of acceptable quality.

Environmental monitoring

Uranium mining operations, in co-operation with the Environmental Affairs Department of the Ministry of Environment and Tourism, continue to actively monitor environmental issues of concern. Best practices and shared experiences are encouraged by participatory environmental planning and management to promote effective waste management practices. In addition to the SEMP, Namibian Uranium Association members carry out additional environmental monitoring, verified by the government, to ensure that the mining footprint is as small as possible. Stringent water-saving measures, air quality and biodiversity monitoring, as well as the implementation of mitigation measures for adverse impacts and environmental training of staff are examples of these efforts.

Well-established environmental monitoring programmes approved under the environmental clearance certificate granted by the Ministry of Environment and Tourism continue to operate. Rössing works to continuously improve environmental management programmes to maximise benefits and minimise negative impacts. Key environmental management programmes include energy efficiency and greenhouse gas emissions, air quality control (including emissions of dust and other impurities, as well as noise and vibration), water use, waste management (both mineral and non-mineral), chemical substance management and land use management (including biodiversity, rehabilitation and closure).

The mineral waste generated by Rössing Uranium in 2020 amounted to a total of 18.7 million tonnes (8.7 million tonnes of tailings and 10.0 million tonnes of waste rock). Tailings were deposited in the existing tailings storage facility. The tailings footprint has shown a slight increase with 1.4 ha due to starter walls being built for the future deposition in the Y3 Paddy.

Waste rock was deposited in existing rock dumps close to the open pit with no extension of the footprint. The total mineral waste inventory generated by Rössing over the last 44 years amounts to roughly 1.47 billion tonnes covering a total footprint of 1 488 ha.

Since 1980, Rössing has been recycling 60 to 70% of its water. The 2020 Rössing operating plan set and achieved a target for desalinated freshwater usage of 2.9 million m^3 supplied by NamWater. Saline groundwater from the Khan River aquifer used for haul road dust suppression took only 19.4% of the permitted volume in 2020.

Well-established environmental monitoring programmes approved under the environmental clearance certificate (ECC) granted by the Ministry of Environment and Tourism continued during this reporting period. The LHU remains fully permitted to resume mining, production and uranium exports. Noteworthy were the LHU's successful applications to:

- the Ministry of Environment, Forestry and Tourism for the extension of the environmental clearance certificate (ECC) for ML140 and ML172;
- the Ministry of Agriculture, Water and Land Reform for extension of its Wastewater and Effluent Disposal Exemption Permit. A permit extension was issued for a period of five years.

The LHU continued submitting compliance reports as stipulated under various permitting and licencing conditions.

Environmental activities at Husab included continued compliance (routine audits, inspections, ECC renewals, permit condition management, etc.) and bio-physical (planned surface and groundwater, air quality, environmental radiation, biodiversity, etc.) monitoring. An application for an on-site nursery for restoration trials was filed and initiated. Good progress was made on the social component of the mine rehabilitation, restoration and mine closure plan. Water requirements continue to be met by desalinated water supply through agreements with NamWater and Orano. An application for a permit to allow pit dewatering to be used for dust suppression was made to the relevant authorities. A closed loop circuit in the Husab processing plant facilitates continual water recycling and the final treated effluent from the sewage treatment plant is used for dust suppression. Husab continue to minimise raw water consumption through wastewater recycling from the dam to the processing plant.

Liaison with government agencies, through meetings and site visits, is ongoing. Bi-annual compliance reports on mining and exploration activities are verified through external second-party and third-party audits. Amendments made to Husab environmental impact assessments from 2017 to 2019 were assessed through scoping reports issued for approval by government.

An EIA for the Tumas Project mining lease application commenced in 2020. Baseline studies, including on groundwater, flora, fauna, radiation, air quality, noise, archaeology and socio-economic impacts, were completed and the results compiled in a Scoping Report that forms the basis of the assessment and Environmental Management Plan. Environmental monitoring includes groundwater and dust sampling, the collection of weather data, and monitoring of native flora. The RMR's Safety, Health and Environmental Control Officer (SHECO) and its Radiation Safety Officer ensure compliance to the company's Environmental Management Plan (EMP) for exploration activities and the Radiation Management Plan (RMP).

Site rehabilitation

All Namibian uranium operators adhere to the Mine Closure Framework of the Chamber of Mines of Namibia. The framework provides guidance to the mining industry on developing relevant, practical and cost-effective closure plans and establishes minimum requirements for members bound by the Chamber's Code of Conduct and Ethics.

The Rössing Environmental Rehabilitation Fund, established to provide for the mine's closure costs, complies with statutory obligations and stipulated requirements of the government. The fund requires an annual contribution by the mining company to provide for the total cost of the eventual closure of the mine, expected in 2025. At the end of December 2020, the fund had a cash balance of NAD 1 120million (USD 76 million).

Corporate social responsibility

Members of the NUA have undertaken corporate social responsibility projects for more than three decades, with over 20 ongoing to address themes such as economic advancement, social progression, education and training, hunger and poverty, water supply, sanitation and youth employment.

Rössing also promotes healthy, safe and environmentally responsible lifestyles among neighbouring communities, and makes direct contributions to initiatives targeting biodiversity protection, conservation education, health and safety (including HIV/Aids), and waste management. Total investment in these corporate social activities in the year 2020 amounted to NAD 26 million (USD 1.6 million), including the donation of an Oxygen Plant to the public hospital in the main port city of Walvis Bay.

The LHU remains committed to addressing social aspects such as local procurement, recruitment, employee development and involvement in the community. During this reporting year, the LHU made donations to the Namib Anti-Poaching Unit and the Ministry of Environment, Forestry and Tourism for use in the Namib Naukluft National Park. The provision of equipment and fuel to these organisations assists them in continuing critical conservation work.

The Husab mine remains committed to addressing social aspects such as local procurement, recruitment and employment, involvement in social responsibility programmes, training, education and sound environmental management practices.

Orano engages with stakeholders at local, regional and national levels in the areas of economic development, education, culture and sport. Orano fully supports the Harambee Prosperity Plan.

Bannerman Resources, even at an early stage of mine development, has focused on education and tourism as part of its social programme, for example supporting over 2 000 disadvantaged primary school children in the Erongo and other regions in Namibia.

RMR's CSR activities are focused on early childhood development, empowering people and communities through sports, promoting a sustainable environment, and community support through food aid.

Atomic Energy and Radiation Protection Act, Act No 5 of 2005

The Atomic Energy and Radiation Protection Act (Act No.5 of 2005) was gazetted on 16 January 2012. Administered by the National Radiation Protection Authority, it provides for the regulation of all activities associated with radiation sources, radioactive or nuclear material.

The primary purposes of the act are to protect people against the harmful effects of radiation, minimise environmental pollution that may be caused by radiological contamination, ensure the safety of facilities and radiation sources, and guarantee that Namibia meets its obligations within the context of international legal instruments in the sector of radiation or nuclear technologies.

Regulatory regime

Namibia has hosted uranium mining for more than 45 years. The sector is governed by a range of comprehensive legislations for uranium exploration and mining, starting with the Namibian Constitution, which provides for the protection of the environment and the welfare of people. Uranium mining is regulated by the Minerals (Prospecting and Mining) Act 33 of 1992. Section 2 of this Act vests all rights with respect to minerals to the state. Environmental issues are regulated by the Minister of Environment and Tourism. The Minister of Mines and Energy may not issue a mineral licence before the applicant has obtained an environmental clearance certificate.

Furthermore, the Minerals (Prospecting and Mining) Act 33 sets the terms and conditions for granting exploration and mining licences. Section 102 of this Act prohibits the processing, import, export or possession of source material without the Minister's written authorisation. Health and safety aspects relating to the minerals industry are administered in terms of the previous Mines, Works and Minerals Ordinance 20 of 1968.

Namibia's Environmental Management Act underlines the importance of consultation with interested and affected parties. It promotes sustainable environmental management and use of natural resources by establishing principles for decision making and environmental impact assessment regulations.

Namibia is party to the Nuclear Non-Proliferation Treaty, has had a comprehensive safeguards agreement in force since 1998, and in 2000 signed and ratified the Additional Protocol.

In July 2008, the government established the Epangelo Mining Company to participate in the mining sector, and as per the provisions of the Minerals (Prospecting and Mining) Act, to acquire mining rights and equity by concluding joint ventures with existing companies. The Namibian government is the sole shareholder of Epangelo. Namibia has identified uranium as a strategic mineral and potential source of energy, expressing its desire to enhance economic development through potential local fuel cycle facilities and by considering nuclear power to augment its energy needs.

Uranium requirements

At present, Namibia has no nuclear power generating facilities. Namibia produces power locally and imports about half of its electricity, with the bulk of this being supplied by Eskom in South Africa and the balance by ZESCO in Zambia.

National policies relating to uranium

The government has designated its uranium resources as strategic and controlled minerals that must be treated differently from other minerals because of, among other reasons, the risk of proliferation, radiological risks and their use as fuel for generating electricity.

Given the special nature of uranium and its radiological and fissile properties, the government is developing responsive regulatory frameworks to address health, safety, research and development applicable to the nuclear fuel cycle. Because Namibia is considering the development of commercial nuclear power to promote energy security and meet its increasing energy needs without increasing greenhouse gas emissions, it has developed a Nuclear Fuel Cycle Policy to examine the potential value addition of yellow cake.

Uranium exploration and development expenditures and drilling effort – domestic

(NAD – Namibian dollars)

	2019	2020	2021 (expected)
Industry* exploration expenditures	76 949 270	189 504 970	278 981 926
Industry* development expenditures	7 449 250	2 386 900	2 736 029
Total expenditures	84 398 520	191 891 870	281 717 955
Industry* exploration drilling (m)	32 957	47 423	73 240
Industry* exploration holes drilled	1 030	691	1 258
Industry* development drilling (m)	16 600	5 319	9 417
Industry* development holes drilled	NA	NA	NA
Total drilling (m)	49 557	52 742	82 657
Total number of holes drilled	NA	NA	NA

* Non-governmental expenditure.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	295 401	311 062	80
In situ leaching	0	11 760	11 760	11 760	80
Total	0	11 760	307 161	322 822	80

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	249 120	256 442	80
Heap leaching* from OP	0	0	46 281	54 619	80
In situ leaching	0	11 760	11 760	11 760	80
Total	0	11 760	307 161	322 822	80

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Intrusive	0	0	225 921	233 243
Surficial	0	0	69 480	77 818
Sandstone	0	11 760	11 760	11 760
Total	0	11 760	307 161	322 822

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	154 984	178 791	80
In situ leaching	0	7 920	7 920	7 920	80
Total	0	7 920	162 904	186 711	80

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	135 323	147 434	80
Heap leaching* from OP	0	0	19 662	31 357	80
In situ leaching	0	7 920	7 920	7 920	80
Total	0	7 920	162 904	186 711	80

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Intrusive	0	0	122 368	134 479
Surficial	0	0	32 616	44 312
Sandstone	0	7 920	7 920	7 920
Total	0	7 920	162 904	186 711

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	57 000

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	150 700

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (actual)
Open-pit mining*	136 744	5 477	5 412	147 633	5 753
Total	136 744	5 477	5 412	147 633	5 753

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (actual)
Conventional	136 307	5 477	5 412	147 196	5 753
Heap leaching	437	0	0	437	0
Total	136 744	5 477	5 412	147 633	5 753

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (actual)
Intrusive	120 295	5 477	5 412	131 184	5 753
Surficial	16 449	0	0	16 449	0
Total	136 744	5 477	5 412	147 633	5 753

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
402	7	0	0	4 957	92	53	1	5 412	100

Uranium industry employment at existing production centres

(Person-years)

	2019	2020	2021 (expected)
Employment directly related to uranium production	3 231	3 319	3 778

Short-term production capability

(tonnes U/yr)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	7 200	7 200	0	0	7 200	7 200
2035				**2040**			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	7 200	9 800	0	0	7 200	9 800

Nepal*

Uranium exploration and mine development

Historical review

Since 1972, the Department of Mines and Geology (DMG) has been engaged in the exploration of uranium resources in Nepal through ground radiometric and spectrometric surveys.

A ground radiometric survey was initiated in 1972 over part of the Palung and Ipa granites of the Makawanpur and Lalitpur districts.

Systematic ground exploration for uranium in sedimentary rocks, using scintillation counters, was launched in 1981. From 1981 to 1987, radiometric surveys covered about 8 000 km^2 of the Siwalik Range.

In 1982, radiometric surveys were carried out in the Thumki-Jagat and Kakani-Panchmane areas, north of the Kathmandu valley. About 100 anomalies were identified during these reconnaissance surveys. Based on this work, a follow-up ground radiometric survey covering about 1 200 km^2 was carried out between the Kamala River and Narayani River from 1988 to 1990. Mineralisation was observed in the Tinbhangale area of Makawanpur district, where uranium grades of up to 0.13% U were recorded.

From 1992 to 1994, preliminary and follow-up ground radiometric exploration was carried out over part of the Baitadi, Bajhang and Darchula districts. Exploration covering an area of about 150 km^2 was conducted between the Mahakali River and the Jamari Gad area of the Baitadi and Darchula districts. Uranium contents of up to 0.92% U were observed in bedrock and float.

By 2011, the DMG had identified 24 uranium occurrences in Nepal, mainly within the Siwalik sandstone, and in quartzites and pegmatites/granites. A subeconomic uranium occurrence was identified at the Tinbhangale (Makawanpur) locality estimated at 35 tU. From 2012 to 2015, uranium and thorium exploration, sponsored by a Technical Cooperation project between the DMG and the International Atomic Energy Agency, was completed in this area.

From 2014 to 2015, prospecting was completed in the Bangabagar-Baggoth and Gorang areas of the Baitadi district. And from 2016 to 2017, U and Th exploration and radiation hazard mapping was completed in the Shivpuri area near Kathmandu.

From 2014 to 2017, radioactivity anomalies were identified in sandstones in the Lomangthang area of the Upper Mustang region. Additional IAEA/DMG-sponsored prospectivity mapping was delayed due to challenges with accessing this remote area.

Uranium potential in sandstones (tabular sandstone and roll-front sandstone type)

There is potential for Nepal to host economic uranium deposits, and the most promising targets are sandstone-type deposits. However, the challenges associated with access, remoteness, environmental concerns and protected areas are significant.

Small and irregular uranium mineralisation showings have been discovered in the upper parts of the Middle Siwalik and the basal part of the Upper Siwalik Formations in Central Nepal. Coarse-grained sandstones that may have high permeability, and the presence of reductants, are favourable for the occurrence of sandstone-type uranium deposits. The Siwalik Group was

* Report prepared by the NEA/IAEA, based on IAEA Technical Cooperation Project reports.

deposited from the Mid-Miocene to the Lower Pleistocene. The Group is composed of shale, claystone, mudstone, sandstone and conglomerates, mainly of fluviatile origin. Plants, as well as invertebrate and vertebrate fossils and coalified plant remains (fossil wood, lignite layers, etc.) are common. The Palung two-mica peraluminous granite complex located to the north of the mineralised areas may have represented a major uranium source for these deposits. The uranium is associated with coal material in gritty to pebbly arkosic sandstone. The mineralised sections are 1-5 m in thickness and 500 m long at the Tinbhangale locality. Uranium contents from 10-1 308 ppm (0.001-0.13% U) have been measured in chip and channel samples. Uranium minerals are tyuyamunite in the oxidised zone and uraninite and coffinite in the unoxidised zone.

From 2014 to 2017, exploration in the remote Lomangthang area, Upper Mustang region, identified an extensive area (10 km x 3 km) of anomalous radioactivity, possibly associated with tabular or roll-front sandstone-type deposits. The radioactivity occurs within young (8-2 Ma), poorly consolidated interbedded sandstones and siltstones that occur close to U-rich granite source rocks. The sandstones also appear to contain organic material that could act as reductants for uranium deposition.

Uranium potential related to sodium metasomatism (Na-Metasomatite Type)

In 1982, a radioactivity showing (>3 000 cps) a few hundred metres above the Main Central Thrust was identified along the Chhuling Khola River. The mineralisation is represented by brannerite disseminated in an albitised rock. These features are typical of uranium deposits associated with Na metasomatism which may present large uranium resources.

This "Gorkha radioactivity occurrence" is associated with a large (~10 km by ~2 km) saprolite-weathered nepheline syenite body. Scintillometer radioactivity (>5 000 cps BGS-1SL) was discovered during a regional scale field-mapping programme conducted by the DMG. Subsequent spectrometer surveys identified up to ~475 ppm eU and up to ~730 ppm eTh at the locality. The nepheline syenite body has high background radioactivity throughout and is well foliated (schistose to gneissic). The surface of the body and edge/contact with phyllites/country rocks are associated with anomalous radioactivity and appear to be important exploration targets. A saprolite-weathered nepheline syenite body has anomalous radioactivity relative to the background. Weathered material is not competent (no longer considered rock) and it is verging on becoming soil. "Fresh" (weak to no alteration) nepheline syenite also appears to be associated with anomalous radioactivity. New road cuts and roadwork helped uncover new rocks and outcrops.

Altered nepheline syenite rock has anomalous radioactivity relative to the background. The highest radioactivity observed was in altered nepheline syenite coincident with fractures (>20 times that of "normal" syenite). If the entire radioactivity is attributed to uranium, one fractured sample would have 900-1 000 ppm eU. Radioactive fractures are magnetic and associated with iron oxides and hydroxides (magnetite ± hematite ± limonite). Near this fracturing, the nepheline syenite is altered, but still competent and un-weathered. Albite/feldspars are converted to white clays and sericite (saussuritisation). Mafic minerals ± nepheline have been converted to chlorite. This is not interpreted to represent a low-temperature alteration system and is most likely the result of hydrothermal alteration processes. Field observations suggest that either a metasomatite or granite-hosted uranium deposit model may be valid for the Gorkha radioactive occurrence.

Uranium potential of the Banku quartzite ("vein type")

Uraninite and autunite mineralisation has been discovered in outcrops over the Banku quartzite in West Nepal over 1 500 m and with a thickness of 1.5-8 m. Uranium oxides occurring in millimetre thick veinlets indicate the presence of a hydrothermal system that was able to leach and concentrate uranium in the form of uranium oxide. Surface radiometry has yielded total counts of 3 500-10 000 cps (GAD 6 scintillometer). Outcrop sample analyses have given uranium contents of 137-9 213 ppm U (0.04-0.9% U). This area is considered as prospective for the discovery of "vein-type" uranium mineralisation associated with quartzites.

Uranium potential from unconventional resources (phosphate, lignite-coal, black shale types)

The most important phosphate occurrence in Nepal has been identified in the Baitadi carbonate formation in the Lesser Himalaya of Far East Nepal, of the middle Proterozoic age (1 200 to 1 000 Ma). The phosphate-rich horizon is confined in the stromatolitic Massive Cherty Dolomite member among seven lithological members. It extends laterally over more than 25 km. Its thickness varies from a few metres to 18 m. The P_2O_5 content varies from 10 to 32 wt.%. To evaluate the economic potential of the Baitadi Formation, it would be necessary to identify the average phosphate content.

In Nepal, coal occurs in four stratigraphic horizons: Quaternary lignite of the Kathmandu valley, Siwalik coal of the Sub Himalayan/Churia Range, Eocene coal of western and mid-western Nepal, and Gondwana coal. The uranium content of these horizons is unknown. The uranium content of the lignite horizon from the Kathmandu valley may have significant uranium contents owing to the presence of uranium showings in the gneissic muscovite-tourmaline granites and pegmatites occurring to the north of Kathmandu city, with drainage directed to the Kathmandu valley. Only the Quaternary lignite of the Kathmandu valley and the Eocene coal has been mined for domestic needs. The resources from the Quaternary lignite and the Eocene are quite limited and even if they were relatively rich in uranium, their recovery will not be of economic interest. However, due to the presence of uranium-rich othogneisses surrounding the Kathmandu depression, it is likely that these lignites are significantly enriched in uranium. As they are also used for domestic needs, they may also represent an environmental concern that could be evaluated.

Black shales also occur in various parts of Nepal, but they are generally metamorphosed and deformed, and their uranium content is not known. Therefore, the probability of having significant uranium resources in this type of lithology seems to be limited given the present state of knowledge.

Recent and ongoing uranium exploration and mine development activities

Nepal is currently building its capacity to explore for uranium deposits and to analyse geological samples for U and Th. The IAEA continues to support Nepal through national and inter-regional technical co-operation projects on uranium exploration and production (2016-2023). These projects support national capacity building for the exploration and mining of U and Th resources, with a focus on training, equipment procurement and technology transfer. Priority exploration targets include the Tinbhangale and Upper Mustang Lomanthang sandstone-type uranium occurrences.

Identified conventional resources (reasonably assured and inferred resources)

Nepal has no known uranium resources.

Undiscovered conventional resources (prognosticated and speculative resources)

Resources are roughly estimated at 35 tU at Tinbhangale in the Siwalik region.

Unconventional resources and other materials

No unconventional resources have been identified.

Uranium production

Historical review

No uranium production has occurred.

Status of production facilities, production capability, recent and ongoing activities and other issues

No uranium production is planned

National policies relating to uranium

The regulations of the Mines and Mineral Act guide the exploration of all minerals in Nepal. Uranium along with rare earth elements are treated as strategic minerals and exploration activity is conducted exclusively by the DMG. The Environmental Protection Act and regulations offer specific guidance for uranium exploration. The national mineral policy applicable for the development of uranium production states that uranium exploration, production and development is the responsibility of the central government. A specific environmental policy has not been established for the nuclear fuel cycle, but the overall environmental policy is guided by the Environmental Protection Act and regulations. Safety and social development policies have been incorporated into a proposed nuclear bill under consideration by the Parliament. Regulatory bodies include: the Department of Mines and Geology, the Department of the Environment, and the Nuclear Material Management Division. The proposed Nuclear Act developed by the Ministry of Education, Science and Technology (with the assistance of the IAEA) will provide direction for interactions among the regulatory bodies and act as a co-ordination mechanism for the regulatory process, decision-making and involvement of interested parties and stakeholders in Nepal and abroad.

Niger*

Uranium exploration and mine development

Historical review

Uranium exploration began in 1956 in the Arlit area of Niger within the Tim Mersoï sedimentary basin, and uranium was first discovered in sandstone at Azelik in 1957 by the French Bureau de Recherches Géologiques et Minières (BRGM). The French Atomic Energy Commission initiated further studies of the sandstone, which were taken over by the Compagnie Générale des Matières Nucléaires (COGEMA) and resulted in the discoveries of Abokurum (1959), Madaouela (1963), Arlette, Ariege, Artois and Taza (1965), Imouraren (1966) and Akouta (1967).

The Société des Mines de l'Aïr (Somaïr) was created in 1968 and started production from the Arlette deposit in 1971 by shallow (60 m depth) open-pit mining. From 1971 to 1988, acid heap leaching was used at Arlit, producing 200-600 tU/yr, for a total of 5 900 tU over this 17-year period. The uranium recovery rate achieved was low (50% or less) and from 1988 to 2009 more than 10 Mt of low-grade ore (0.08% U average grade) had been stockpiled. In 2009, after conducting tests over several years, Somaïr restarted heap leaching using an improved process to achieve recovery rates above 85%. Since the start of operations in 1971, about 70 000 tU were produced at the Somaïr mine. In 2017, due to tough uranium market conditions, Somaïr entered a plan to reduce annual production to 1 700 tU.

The Compagnie Minière d'Akouta (Cominak) was set up in 1974 and started production from the Akouta and Akola deposits, near the town of Akokan. This is an underground operation at a depth of about 250 m. Production has now switched to the deposit of Ebba/Afasto, south of Akouta and Akola. Since the start of operations in 1978, more than 70 000 tU were produced at Cominak mine.

In 2004, COGEMA and the government of Niger signed an agreement to undertake a major exploration programme. In subsequent years, both Somaïr and Cominak were involved in exploration solely for the purpose of better evaluating previously discovered deposits. Somaïr delineated the Taza Nord deposit, while Cominak evaluated a mineralised area south-east of the Akola deposit.

Development of the large Imouraren deposit about 80 km south of Arlit was confirmed in January 2008. In 2009, Areva SA (now Orano SA, as of January 2018) was awarded a mining licence and a joint venture agreement was signed to develop Imouraren, but it was shelved because of unfavourable market conditions.

In 2006, the China National Nuclear Corporation (CNNC) signed an agreement to develop the Azelik-Abokurum deposit and a new company, Société des Mines d'Azelik (Somina), was created in 2007 for this purpose. About 670 tU were produced up to 2014, when the mine was put in care and maintenance.

All uranium deposits in Niger are located within the Tim Mersoï Basin, a sub-basin of the Illemmenden Basin. The Tim Mersoï Basin is close to the main Arlit-In Azaoua fault. Uranium is mined close to the twin mining towns of Arlit and Akokan, 900 km north-east of the capital, Niamey (more than 1 200 km by road), near the southern border of the Sahara Desert and the

* Report prepared by the NEA/IAEA, based on company reports and government data.

western range of the Aïr Mountains. The concentrates are trucked to ports in Benin and the majority are exported to the Malvési conversion facility in France.

Uranium exploration in Niger was revitalised in 2007 as the price of uranium increased. Six new exploration permits were granted that year and by 2011 uranium exploration activities were being carried out on 160 concessions by foreign companies. From 2001 to 2016, 356 uranium exploration permits were registered. However, since 2011, there have been increasing geopolitical tensions in the region, resulting in foreign companies like Paladin and URU Metals ceasing exploration activities in Niger.

Following a 2006 agreement in which Areva agreed to increase royalty payments to the government by 50%, development of the Imouraren deposit, about 80 km south of Arlit and 160 km north of Agadez, was announced in January 2008. In January 2009, Areva was awarded a mining licence. The Imouraren SA mining company was established, with Areva NC Expansion (86.5% Areva, 13.5% KEPCO) holding a 66.65% interest and Sopamin of Niger holding the remaining 33.35%. Production was expected to be 5 000 tU/yr for 35 years. The deposit covers 8 km by 2.5 km. Orano reports 213 722 tU of probable reserves at 0.072% U plus 62 584 tU of indicated and 2 879 tU of inferred resources. Average depth is 110 m and maximum thickness 60 m. At full production, the project's heap leaching facility will process 20 000 tonnes of ore per day with an expected 85% rate of recovery. Excavation of the first pit started in mid-2012. In May 2014, uranium prices were not sufficient to allow profitable mining of the deposit and the Nigerien government and Areva agreed to suspend development and set up a joint strategic committee that will determine when mining should start.

In 2008, GoviEx Uranium held two exploration properties of 2 300 km^2: one near the Arlit mine, including the Madaouela deposit, as well as 2 000 km^2 near Agadez. In August 2008, Cameco bought an 11% share in the company for USD 28 million, with an option to increase its share to 48%. The government of Niger has the right to hold a 10% carried interest and the option to purchase a further 30% share when the Nigerien mining company is incorporated. The GoviEx drilling programme commenced in August 2008. The work programme was based on three objectives: i) resource delineation drilling of Marianne and Marilyn deposits; ii) exploration and resource definition drilling on the Madaouela South deposit area; and iii) exploratory drilling between the known deposits. As of February 2010, a project-wide total of 584 000 m had been drilled by GoviEx.

Global Atomic Fuels Corp. (GAFC), a private Canadian company, has six exploration permits (728.8 km^2) located in the north of Agadez, four at Tin Negouran (the "TN permits") and two at Adrar Emoles (the "AE permits"). The Adrar Emoles permit hosts the Dasa deposit, a sandstone basal-channel type deposit. From 2010 to 2014, GAFC drilled 969 holes (867 rotary drill holes and 102 diamond drill holes), for a total of >120 000 m and in January 2014 released an initial inferred resource estimate, which totalled 43 850 tU grading 0.054% U, using an 0.0085% U cut-off. In June 2014, GAFC announced internal resource estimates ranging from 64 600 tU at 0.049% U (0.0085% U cut-off), to 29 600 tU grading 0.29% U (0.127% U cut-off). The base case appeared to be 36 500 tU grading at 0.222% U (0.085% U cut-off).

URU Metals Limited reported a South African Mineral Resource Committee (SAMREC) compliant inferred resource of 1 654 tU on their In Gall deposit and in 2011 continued to drill the Aboye, Akenzigui and Fagochia targets within their Irhazer and In Gall permits. Project commitments elsewhere caused URU Metals to take steps to terminate activities in Niger by 2014.

In December 2010, Paladin completed the takeover of NGM Resources Ltd, the owner of the local company Indo Energy Ltd that held concessions in the Agadez region. NGM Resources had announced an inferred mineral resource of 4 320 tU. In early 2011, Paladin carried out a drilling programme that further defined targets for follow-up and information from the drilling was used to plan a 15 000 m drilling campaign. However, this was put on hold because of security concerns. All fieldwork has ceased and *force majeure* was requested from the government authorities for an indefinite suspension of further expenditures.

In 2011, GazPromBank Niger Minerals SARL, a Russian company, was granted two uranium licences (Toulouk) located in the Tim Mersoï Basin. In March 2017, the company submitted a pre-feasibility study through which it declared JORC compliant inferred resources of sandstone-type tabular mineralisation with 29 630 tU at a grade of 0.0157%, a roll-front type deposit containing 17 000 tU with grades varying from 0.04% to 0.06% and a surficial sandstone-type deposit containing 8 237 tU at a grade of 0.0252% U.

On 20 September 2013, Pan African Minerals Ltd was granted four uranium licences (Ouricha 1 and 2 and Tegmert 1 and 2) located in the Agadez area. Pan African Minerals planned to invest at least USD 20 million in exploration activities during the next three years.

Recent and ongoing uranium exploration and mine development activities

Dasa project

In 2017-2018, Global Atomic Corporation (GAC; formerly GAFC) commenced a new drilling programme targeting various areas of the Dasa project and a total of 59 holes amounting to 26 479 m were completed. This delineated higher-grade mineralisation within 300 m of the surface. The drilling was focused on areas of faulting associated with a graben structure and results improved understanding of the distribution of mineralisation within the deposit and confidence in the geological model. This resulted in an upgraded classification of resources from inferred to indicated

The Dasa project mineral resources were first estimated and reported by CSA Global in April 2017, then updated in June 2018 and June 2019. Mineral resources were reported in two parts; those that have potential for extraction by open pit, and the deeper, higher-grade material outside of the open pit that may be amenable to underground mining. The open-pit mineral resources are the parts of the deposit above a cut-off of 320 ppm eU_3O_8. Higher-grade material above a cut-off grade of 1 200 ppm eU_3O_8 outside of the optimised pit shell was considered for underground mining. Some areas could also be considered for ISL.

Dasa mineral resources as at 1 June 2019

(NI 43-101 compliant)

Category	Ore (Mt)	Grade (% eU)	Uranium (t)
Indicated OP	25.59	0.145	37 118
Indicated UG	0.71	0.275	1 962
Total indicated	26.30	0.148	39 080
Inferred OP	18.93	0.115	21 771
Inferred UG	3.38	0.352	11 924
Total inferred	22.31	0.151	33 695

In May 2020, GAC completed a preliminary economic assessment (PEA) using a base case uranium price of USD 35/lb (USD 91/kgU) to mine the flank zone of the Dasa deposit. GAC planned to use conventional underground mining and proven processing technology that is currently being used at existing uranium mines in Niger, targeting an initial production of 44 Mlb (16 900 tU) with an average processed grade of 0.46 %U. The PEA cash costs amounted USD 16.72/lb U_3O_8 (USD 43.47/kgU), including corporate and all other off-site costs, and an all-in sustaining cost of USD 18.39/lb U_3O_8 (USD 47.81/kgU).

An environmental impact statement (EIS) was completed and filed with the Niger government in July 2020. The Dasa project site hydrogeology drilling and water flow test work was completed and a tender for final geotechnical diamond drilling for the feasibility study was issued. Two public hearings in Niger regarding the EIS were organised, one in the Dasa project area and the other in the capital city of Niamey.

In August 2020, pilot plant trils were initiated in the process research Ortech facility in Canada to confirm and optimise the processing plant flow sheet. The tests demonstrated the viability of the uranium recovery process detailed in the May 2020 PEA.

On 25 September 2020, GAC announced that it had applied for a mining permit for the Dasa project. In December 2020, a presidential decree granting the mining permit was approved by the Council of Ministers for the project. GAC also received three-year permit extensions for each of its six exploration properties in Niger. These include the Adrar Emoles 3 permit hosting the Dasa and Dajy (6 540 tU) deposits, the Adrar Emoles 4 permit, hosting the Isakanan deposit (13 080 tU) and the Tin Negouran 1, 2, 3 and 4 permits, hosting the Tin Negouran deposit (3 850 tU).

In November 2021, GAC issued an NI 43-101 compliant, Phase 1 Dasa project feasibility study (FS). It confirmed that the project is economically compelling at a price of USD 35/lb U_3O_8 (USD 91/kgU). Based on the FS, the Board of Directors made a decision to proceed with production at the Dasa project. The FS is focused solely on Phase 1, primarily comprised of the flank zone, and represents the initial 12 years of the project and less than 20% of the Dasa mineralisation. The FS is an update from the PEA filed in May 2020.

2019-2020 exploration expenditures (Canadian dollars)

	2019	2020
Management fees, salaries	1 064 257	937 524
Equipment, fuel and maintenance	33 538	63 196
Camp costs	108 367	114 439
Drilling, assays	845 445	2 201 685
Security costs	95 194	140 225
Travel and other costs	79 964	5 174
Taxes and other fees	1 088	77
Total	2 227 853	3 462 320

In addition to Dasa, two other deposits are located on the Adrar Emoles permits, Dajy and Isakanan. The Dajy deposit is located along the major northeast-southwest trending Azouza Fault that hosts the Azelik and Dasa deposits, some 30 km SE of Imouraren. Whereas Dasa can be traced to the surface, Dajy occurs at depth. Dajy uranium mineralisation is hosted in three sandstone units over a 3.5 km long and 400 m wide area. The Dajy deposit contains 6 540 tU grading 0.0584% U (inferred resources). The Isakanan deposit, located 15 km south of the Dasa and Dajy deposits, hosts 13 080 tU grading 0.076% U (inferred resources). The Tin Negouran permits host the Tagadamat deposit, where mineralisation occurs within surface paleochannels along a 3-km strike, with potential for open-pit mining and heap leach processing. The Tagadamat deposit hosts 3 850 tU grading 0.015% U (inferred resources). An environmental baseline study was completed in 2009, but the project was put on hold until 2020.

Madaouela project

In March 2017, GoviEx began a drilling programme focused on expanding shallow near-surface uranium mineralisation associated with the Miriam deposit. The 4 000 m drilling programme was conducted on a 100 m grid at Madaouela to an expected average depth of approximately 100 m (40 drill holes). However, the drilling did not result in additional resources. On 15 November 2017, GoviEx was granted an exploration permit for Agaliouk, which is adjacent to the Madaouela deposit. The Agaliouk exploration permit adds 4 488 tU in the measured and indicated categories and 3 596 tU in the inferred category.

GoviEx developed a NI 43-101 integrated development plan for five deposits (Marianne, Marilyn, Miriam, Madaouela South North East [MSNE] and Maryvonne). The plan is based on detailed pre-feasibility geological studies that considered metallurgical testing and processing options, mine design, infrastructure, rock mechanics, tailings and heap leach and hydrogeological and environmental impacts. As of November 2017, NI 43-101 compliant resources at Madaouela totalled 42 603 tU of measured and indicated resources and 10 647 tU of inferred resources. An open-pit mine on at least part of the deposit, followed by underground room and pillar mining with conventional processing, is expected to produce 1 030 tU/yr over 21 years, with potential for expanding the resource. Production is expected to begin by 2022. The environmental and social impact assessment for the project was filed with the Nigerien government in March 2015 and a mining licence was obtained in January 2016.

Madaouela mineral resources (cut-off: 0.04% U) as of 13 November 2017

(NI 43-101 compliant)

Deposit	Classification	Ore (Mt)	Grade (%U)	U (t)
Marianne/Marilyn	Measured	2.14	0.152	3 252
	Indicated	14.72	0.121	17 808
	Inferred	5.04	0.099	5 012
Miriam	Measured	9.62	0.092	8 817
	Indicated	2.68	0.067	1 791
	Inferred	0.58	0.113	656
MSNE	Indicated	5.05	0.137	6 878
	Inferred	0.10	0.114	111
Maryvonne	Indicated	1.23	0.152	1 861
	Inferred	0.42	0.141	596
MSCE	Inferred	0.72	0.153	1 109
MSEE	Inferred	1.45	0.139	2 012
La Banane	Indicated	1.57	0.139	2 195
	Inferred	1.15	0.110	1 152
	Total Measured	11.76	0.103	12 069
	Total Indicated	25.25	0.121	30 534
	Total Inferred	9.46	0.113	10 647

In 2018, GoviEx reviewed the ore process design of the Madaouela project and determined that the inclusion of membrane separation in the process design could potentially reduce operating and capital costs, which may in turn improve project economics. On 19 September 2018, GoviEx announced the appointment of SRK Consulting (UK) Ltd and SGS Bateman (Pty) Ltd as the consultants to complete a feasibility study for the Madaouela project.

In September 2019, Niger approved the revision to the shape of the Madaouela I mining permit to include 1 550 tU in the measured and indicated categories associated with the Miriam uranium deposit as well as 6 880 tU in the measured and indicated categories associated with the Madaouela South North East deposit, both previously situated within the Agaliouk exploration permit.

In 2020, GoviEx decided to complete an updated preliminary feasibility study and announced the results in February 2021. Open-pit mining is planned to be based on standard truck and shovel operations for the Miriam deposit at a planned rate of 1 Mt per year of ore feed to the process plant. Mining operating and capital costs have been updated with a high degree of confidence as they are based on the current supplier quotes to define owner-operator operating costs of USD 2.30/tonne mined. The Marianne-Marilyn and MNSE-Maryvonne deposits will be mined by room and pillar. Ore mining is designed to be undertaken at a rate of approximately 1.4 Mt per year. Run of mine ore is then planned to be sorted by X-ray fluorescence to remove waste dilution. The sorted ore will be trucked to the process plant at a rate of 1.0 Mt per year.

On 18 February 2021, GoviEx released the results of a mineral reserves estimate. The estimate is based on the mineral resources classified as measured and indicated (as of 2 March 2016), and incorporates technical and economic studies that justify economic extraction. All mineral reserves are classified as probable in accordance with the CIM NI 43-101 codex.

Madaouela probable mineral reserves as of 13 November 2017 (NI 43-101 compliant)

	Ore (Mt)	Grade (%eU)	Uranium (teU)
Open pit			
Miriam	7.78	0.085	6 601
Underground			
Marianne-Marylin	10.48	0.088	9 180
Maryvonne	6.65	0.079	5 273
Total	24.92	0.085	21 054

Open-pit mineral reserves are reported within a designed pit shell at a cut-off grade of 0.03% eU. Cut-off grades are based on a price of USD 50 /lb of U_3O_8 (USD 130/kgU) and uranium recovery of 93%, without considering revenues from other metals. Underground mineral reserves for Marianne-Marilyn and MSNE-Maryvonne are reported at a cut-off grade of 0.06% eU. Cut-off grades are based on a price of USD 50 /lb of U_3O_8 (USD 130/kgU) and uranium recoveries of 89.3%, without considering revenues from other metals. The project's life is forecast to last 20 years, producing an estimated total of 19 100 tU, averaging 950 tU per annum. For the first four years of operation, the expected cash operating costs, excluding royalties and including credits for molybdenum, is USD 47.6 per kgU, with a life of mine cost of USD 57.7 per kgU.

In 2018 and 2019, exploration and evaluation expenditures amounted to USD 1 383 000 and USD 1 211 000, respectively.

Cominak, Somair and Arlit

In 2019-2020, Orano continued exploration and development activities within the Cominak and Somaïr mines perimeters and in the Arlit concession. Somaïr drilled 16 240 m in 2017, 8 150 m in 2018, and was planning 11 863 m in 2019. In October 2018, Somaïr was granted the Artois deposit concession.

In 2018, the government of Niger renewed Pan African Minerals exploration licences (Ouricha 1 and 2 and Tegmert 1 and 2), but no activity was reported in 2019 and 2020.

Mineral reserves (in situ) reported by Orano as of 31 December 2020

Deposit	Classification	Ore (Mt)	Grade (%U)	U (t)
Cominak	Proven	23	0.38	88
Imouraren	Proven	0	0	0
	Probable	306 048	0.070	213 722
Somaïr	Proven	166	0.07	110
	Probable	12 042	0.14	16 434
Total	Proven	189	0.105	198
	Probable	318 090	0.072	230 156

* Does not include mineral resources. Recovery factors: Cominak (89.2%), Imouraren (81.5%), Somaïr (87.9%).

Mineral resources (in situ) reported by Orano as of 31 December 2020*

Deposit	Classification	Ore (Mt)	Grade (%U)	U (t)
Concession Arlit	Inferred	12 845	0.16	20 403
Cominak	Measured	36	0.32	116
	Indicated	31	0.32	100
Imouraren	Indicated	108 668	0.06	62 584
	Inferred	4 394	0.07	2 879
Somaïr	Indicated	22 034	0.13	27 603
	Inferred	16 258	0.14	23 200
Total	Measured	36	0.32	116
	Indicated	130 733	0.069	90 287
	Inferred	33 497	0.139	46 482

* Does not include mineral resources. Recovery factors: Cominak (93%), Concession Arlit (83%), Imouraren (82%), Somaïr (83%).

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

The total recoverable identified conventional resources for Niger, as of 1 January 2021, amounted to 468 048 tU (585 972 tU in situ), compared to 439 388 tU as of the end of 2018. Recoverable reasonably assured resources (RAR) amount to 334 816 tU; inferred recoverable resources total 133 232 tU. The increase of total recoverable resources (28 660 tU) is mainly associated with an increase of resources at the Dasa and Somaïr deposits. Mining depletion in 2019 and 2020 amounted to 5 973 tU and is taken into consideration in the resource figures.

In the <USD 130/kgU cost category, recoverable RAR amount to 257 520 tU (77% of total RAR), inferred recoverable resources to 53 600 tU (40% of total inferred resources).

All uranium deposits in Niger are sandstone-hosted, with average grades of 0.07 to 0.40% U, with 72% of total identified resources in the RAR category and 95% of these are amenable to open-pit mining.

Undiscovered conventional resources (prognosticated and speculative resources)

Total speculative and prognosticated resources in Niger, as of 1 January 2021, amounted to 64 900 tU (unchanged from 2017).

Uranium production

Historical review

Uranium has been produced from sandstone deposits in Niger since 1971 by Somaïr at the Arlit mine, since 1978 by Cominak at the Akouta mine and since 2010 by Somina at the Azelik mine.

The Société des Mines d’Azelik SA (Somina) was established in 2007 to mine the Azelik/Teguidda deposits. Azelik was developed by the China National Nuclear Corporation (CNNC) and came into production at the end of 2010, with the aim of ramping up to 700 tU/yr. It is an open-pit and underground operation using alkaline leach. In August 2014, CNNC announced that Azelik had experienced prolonged project delays, overruns in its construction budget, and low production. In February 2015, CNNC announced that the mine would be closed and put in care and maintenance because of “tight cash flow”.

Somaïr and Cominak were licensed to the end of 2013, and in mid-December 2013, both were shut down for maintenance, pending resolution of negotiations on licence renewals. The mines resumed operation at the end of January 2014 under the terms of a government decree. In May 2014, the government and Areva signed a new five-year agreement for the two mines based on the 2006 mining law and expressing what both sides said was a balanced partnership.

In 2015, production recorded for Niger amounted to 4 116 tU, then decreased to 3 478 tU in 2016, 3 484 tU in 2017 and 2 878 tU in 2018, then increasing slightly to 2 982 in 2019 and 2 991 tU in 2020.

Status of production facilities, production capability, recent and ongoing activities and other issues

Production in 2019 amounted to 2 982 tU, 1 912 tU of which was produced by Somaïr at the Arlit open-pit mine and 1 070 tU by Cominak at the Akouta undergound mine. Production in 2020 amounted to 2 991 tU, of which 1 879 tU was produced by Somaïr and 1 112 tU by Cominak. It is expected that U production in 2021 will decrease by about 25% due to Akouta mine shutdown.

On 24 October 2019, Orano announced that Cominak will end its uranium production on 31 March 2021 due to the exhaustion of ore and high operating costs, and on that date the Akouta mine ceased production after nearly 50 years of service. Since 1978, Cominak has mined the Akouta, Akola and Ebba deposits, producing approximately 75 000 tU from 1978 to the end of 2020.

Production at the Somaïr (Arlit) open-pit mine has been lowered by 30% since 2015 due to weak market conditions. Arlit is expected to continue operating for some time, as additional resources have been added to the project over the last few years that should extend its mine life to the late 2020s. In December 2018, the Nigerien government and Orano negotiated and approved a new five-year agreement (2019-2023) for the Cominak and Somaïr mines.

On 25 September 2020, GAC submitted a mining permit application for the Dasa project and in December 2020 a presidential decree granting the mining permit was approved by the Council of Ministers. GAC has also received three-year permit extensions for each of its six exploration properties in Niger. These include the Adrar Emoles 3 permit hosting the Dasa and Dajy deposits, the Adrar Emoles 4 permit hosting the Isakanan deposit, and the Tin Negouran 1, 2, 3 and 4 permits hosting the Tin Negouran deposit.

On 19 July 2019, GoviEx announced that it had finalised agreements with Niger that stipulate commercial terms to progress the Madaouela project. Under the terms of these agreements, a Nigerien operating company named Compagnie Minière Madaouela SA ("COMIMA") was incorporated by GoviEx into which the Madaouela mining permit is to be transferred. GoviEx and the government of Niger own 80% and 20% shares in COMIMA, respectively.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1		Centre #2	Centre #3	Centre #4	Centre #5	Centre #6
Name of production centre	Arlit (Somaïr)		Akouta (Cominak)	Azelik (Somina)	Imouraren	Madaouela (Comima)	Dasa
Production centre classification	Existing		Existing	Care and maintenance	Planned	Planned	Planned
Date of first production	1971	2009	1978	2010	NA	NA	2025
Deposit name(s)	Tamou, Artois, Tamgak, Taza	Low-grade stockpiles	Akouta, Akola, Ebba, Ebene	Azelik, Teguidda, Abolorum	Imouraren	Miriam, Marianne, Marilyn, MSNE, Maryvonne	Dasa
Deposit type(s)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Recoverable resources (tU)	37 453	NA		9 684	228 932	21 054	28 138
Grade (%U)	0.13	0.08		0.142	0.072	0.085	0.150
Type (OP/UG/HL)	OP	OP/HL	UG	OP/UG	OP/HL	OP/UG	OP/UG
Size (tonnes ore/day)		1 800 kt/yr					
Acid/Alkaline	Acid	Acid	Acid	Alkaline	Acid	Acid	Acid
Type (IX/SX)	SX	SX	SX		SX	SX	SX
Average process recovery (%)	78	Up to 85	93	85	82	82	84
Nominal production capacity (tU/year)	1 700		1 800	700	5 000	950	1 400
Other remarks			Production ended on 31 March 2021				

Ownership structure of the uranium industry

The ownership structure of Niger's six uranium exploration and production companies are set out in the table below:

Somaïr	Cominak	Somina	Imouraren	Comima	Dasa
36.6% Sopamin (Niger)	31% Sopamin (Niger)	33% Sopamin (Niger)	33.35% Sopamin (Niger)	20% Sopamin (Niger)	100% Global Atomic Corp (Canada)
63.4% Orano (France)	34% Orano (France)	37.2% CNUC (China)	57.65% Orano (France)	80% GoviEx (Canada)	
	25% OURD (Japan)	24.8% ZXJOY invest (China)	9% KEPCO		
	10% ENUSA (Spain)*	5% Trend Field Holdings SA			

* In early 2022, ENUSA ended its participation in Cominak.

Employment in the uranium industry

As of 1 January 2018, 898 workers were employed at the Somaïr mine and 776 at the Cominak mine. It is reported that 99% of the workers at these two mines are Nigerien. About 680 workers were employed at the Azelik mine, but due to the cessation of mining operations, only 25 workers have been retained. The Imouraren project employed about 300 during the development stage and is expected to create about 1 400 permanent and up to 3 000 indirect jobs when the facility will be in full production.

Employment in the uranium industry is not available for 2019 and 2020. In the near future, employment in Niger could increase with the development of new mines at Dasa and Madouela. At Cominak, following the closure of mining activities, part of the workforce will be kept to oversee remediation of the site.

Future production centres

In May 2009, development of the Imouraren mine was launched with an initial investment of more than USD 1.9 billion. Once ramped-up to full capacity, production of 5 000 tU/yr for 35 years is expected. Production, originally scheduled to start mid-2015, remains delayed owing to poor market conditions.

GoviEx has completed a PFS and proposed an open-pit/ underground mine development for the Madaouela project, which could go into production after 2022 with a capacity to produce 950 tU/yr at the beginning and plans to reach 5 000 tU/yr when fully operational.

GAC plans to construct its first mine at Dasa, targeting annual capacity of 1 400 tU/yr. In November 2021, GAC started with site infrastructure development, including road upgrades to connect the mine camp to the main highway, new roads to the mine and mill sites. The portal area has been cleared for excavation to begin in January 2022.

Environmental activities and socio-cultural issues

Both mining operations at Somaïr and Cominak have maintained their ISO 14001 certification for environmental management for many years (certification is renewed every three years). Areva maintains that environmental issues, including water preservation, is fundamentally important to their operations. The mandate of the AMAN project, established in 2004, is to study the existing aquifers in the Arlit and Akokan areas to ensure an adequate supply of potable and industrial water is available and not being compromised. Ways to conserve and reduce water consumption have been implemented and over the past 15 years the annual consumption of water at the mines has been reduced by 35%, despite uranium production doubling at Somaïr in the past 10 years.

In April 2010, Areva and local authorities signed a series of protocols and procedures to implement multipartite radiological control of materials and equipment in the streets of Arlit and Akokan, including more stringent monitoring of used materials being taken from the industrial sites.

Somaïr and Cominak manage two hospitals in Arlit and Akokan with technical support centres. First created to provide medical care for the miners and their families, the centres are now largely open to the public free of charge. Imouraren also recently opened a medical centre that treats local residents for free.

As the country's largest private employer, Orano has been contributing to the improvement of living conditions in local communities. In 2010, Orano (then Areva) initiated a social policy and committed EUR 6 million per year (about USD 6.5 million) for the next five years for implementation. Mining activity has resulted in the construction of housing and a modern network of water distribution as well as contributing to the funding of public services and the construction of educational facilities (schools, libraries, lunchrooms, etc.).

In 2018, Orano invested EUR 2 million (about USD 2.2 million) in the Irhazer project in order to develop irrigation systems and agricultural activities in desert areas in the Agadez region. The objective of the project is to contribute to sustainable food safety against poverty.

Studies for the remediation of the Cominak site began in 2002 with the collection of environmental data to inform the closure planning process. The remediation plans have been regularly updated over the subsequent years to include the results of additional data and technical studies, in order to fully inform the possible closure options.

A remediation plan that includes technical, social and community components has been defined in the Detailed Basic Design study to meet three major challenges:

- Technical: ensure lasting stability in terms of public health and safety, reduce as low as reasonably achievable (ALARA principles) the residual impacts as well as the surface area of land subject to use restrictions after the remediation.
- Employees: minimise the social impact of the closure of production activities and ensure fair and equitable treatment of all employees.
- Community: take into consideration and minimise the impacts of the closure on the community by ensuring a sustainable transition, adapted to the needs of the local populations and in keeping with the company's scope of responsibility.

Uranium requirements

There are currently no uranium requirements in Niger. However, it has been reported that Niger has started consultations with the International Atomic Energy Agency and is considering the installation of two civilian nuclear reactors to meet domestic energy requirements and assist in national economic development.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

One of the main objectives of Niger's national uranium policy is to achieve a higher degree of international competitiveness in the industry. In July 2011, President Issoufou stated that he would seek a better price for the country's uranium exports to maximise their value to support economic and social development. About one-third of Niger's export revenue comes from uranium.

In May 2014, the Nigerien government and Areva signed a new five-year agreement for the two mines based on the 2006 mining law, in which the royalty rate will increase potentially to 12% of market value, depending on profitability. The deal also stipulates for the first time that the firms' boards will include Nigerien managing directors – appointed in 2014 for Somaïr, and in 2016 for Cominak. Also, Areva will provide EUR 90 million (USD 97 million) to support construction of a road from Tahoua to Arlit, near the uranium developments, as well as a further EUR 17 million (USD 18.4 million) for development in the surrounding Irhazer Valley. Orano will also build a new headquarters building (Maison de l'uranium) for its operating companies in the capital Niamey at a cost of EUR 10 million (USD 11 million). The government expects more than USD 39 million in additional tax revenues annually from the new Strategic Partnership Agreement. In October 2014, the Nigerien government formally approved the agreement.

Each year's production is sold to joint venture partners, usually in proportion to their equity, at a set transfer price known as "prix Niger". The quantities not sold to joint venture partners, if any, are sold to trading companies at the prevailing spot prices.

Uranium prices

The price of uranium sold to joint venture partners (prix Niger) is proposed by mining companies to the Ministry of Mines, which ultimately decides on its level and duration of validity – usually equivalent to one year. This price is officially published in the *National Gazette* (*Journal Officiel de la République du Niger*) and posted on its website. In case the price determination is made during the year, it is retroactively applied to deliveries already made.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	78	13 680	35 279	81
Open-pit mining (OP)	0	14 542	243 840	299 537	81
Total	0	14 620	257 520	334 816	81

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	78	13 680	35 279	81
Conventional from OP	0	14 542	65 657	74 348	81
Heap leaching from OP	0	0	178 183	225 189	82
Total	0	14 620	257 520	334 816	81

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	14 620	257 520	334 816
Total	0	14 620	257 520	334 816

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	0	17 870	74
Open-pit mining (OP)	0	0	53 600	54 124	81
Unspecified	0	0	0	61 238	75
Total	0	0	53 600	133 232	76

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	0	17 870	74
Conventional from OP	0	0	51 254	51 778	81
Heap leaching from OP	0	0	2 346	2 346	82
Unspecified	0	0	0	61 238	75
Total	0	0	53 600	133 232	76

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	53 600	133 232
Total	0	0	53 600	133 232

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	13 600	13 600

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	51 300	0

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining*	72 780	1 912	1 879	76 571	2 000
Underground mining*	73 359	1 070	1 112	75 541	250
Total	146 139	2 982	2 991	152 112	2 250

* Pre-2018 totals include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	NA	NA	NA	NA	NA
Heap leaching*	NA	NA	NA	NA	NA
Total	146 139	2 982	2 991	152 112	2 250

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	146 139	2 982	2 991	152 112	2 250
Total	146 139	2 982	2 991	152 112	2 250

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
1 032	34.5	0	0	1 570	52.5	389	13.0	2 991	100

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020
Total employment related to existing production centres	3 011	NA	NA
Employment directly related to uranium production	1 478	NA	NA

Mid-term production projections (tonnes U/year)

2021	2022	2025	2030	2035	2040
2 250	2 000	3 400	NA	NA	NA

Mid-term production capability

(tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
1 700	1 700	1 700	1 700	NA	NA	1 700	4 100

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	4 100	7 400	NA	NA	7 400	7 400

Paraguay*

Uranium exploration and mine development

Historical review

The Anschutz Corporation (Anschutz) of Denver, Colorado, started exploration for uranium in south-eastern Paraguay in 1976 after signing a Concession Agreement with the government of Paraguay in December 1975. This agreement allowed Anschutz to explore for "all minerals, excluding oil, gas, and construction materials".

Previously intermittent exploration had been carried out by international oil companies, with insignificant results. The region is known for its limited mining activities and production of high-grade iron ore, mineral pigments, clays, limestone, sandstone, sand and gravel by Indigenous people.

In early 1976, several reports by Anschutz consultants A.F. Renfro, D.G. Bryant and G.E. Thomas covered the geology of eastern Paraguay based on reconnaissance field trips made through the southern Precambrian area, the sedimentary section from north to south, and the alkalic intrusions in the north-central part of a large concession. From field examinations of various rock types and airborne radiometric data, it was concluded that the Anschutz Concession contained areas with good potential for uranium mineralisation. The regional correlation of stratigraphic horizons favourable to uranium mineralisation was shown in that report.

The initial uranium exploration by Anschutz in 1976 covered an exclusive exploration concession of 162 700 km^2, virtually the whole eastern half of Paraguay. This included geological mapping, water sampling, soil sampling and a broad reconnaissance track etch programme, with stations spaced 10 km apart. The station spacing for the track etch survey was subsequently reduced to 5 km in the southern part of the concession. The reconnaissance programme outlined large anomalous zones and Anschutz concluded that the concession in Paraguay constituted a new uranium province in an area underlain by granitic rocks and sandstones.

The initial reconnaissance programme by Anschutz was followed by a programme of airborne radiometric and magnetic surveys, detailed track etch survey, with station spacing of 100 m to 200 m, geochemical stream sediment and soil sampling, and diamond drilling and rotary drilling over selected target areas. In total, some 75 000 m of drilling was completed from 1976 to 1983. Flight line spacing for the airborne radiometric survey was 5 km with a clearance of 100 m above the surface.

Anschutz carried out exploration on behalf of a joint venture with Korea Electric Power Corporation (KEPCO) and Taiwan Power Company (Taiwan Power). Exploration works intersected uranium mineralisation in drill holes ranging from 0.017% eU (equivalent U) to 0.17% eU associated with layers of sub-horizontal sandstones, and higher-grade intersections ranging from 0.1% eU over 10.2 m to 0.3% eU over 0.3 m in sandstones and siltstones. Work was suspended in 1983 due to low uranium prices.

* Report prepared by the NEA/IAEA, based on previous Red Books, UNECE documents and company reports.

Since 2011-2012 the companies that have been working on uranium projects in Paraguay are Uranium Energy Corporation (UEC) through its Paraguayan subsidiaries Transandes Paraguay S.A. and Piedra Rica Mining S.A., and UrAmerica Limited (UrAmerica) through joint ventures with Ita Pora Mining S.A. and Minera Mbujapeju S.A.

In September 2015, UEC requested a two-year suspension of activities due to low uranium prices. Because of this and other administration issues, there was no exploration activity until 2019.

Historic exploration by the Anschutz/Taiwan Power/KEPCO joint venture and by Cue Resources, plus recent exploration by UEC, totalled investments worth approximately USD 50 million.

In conclusion, all known uranium occurrences in the country are found in the eastern part of the country, and most of them are situated in the sandstones in the western flank of the Parana Basin. The age of most major sandstone uranium deposits ranges from Paleozoic to Mesozoic.

In south-eastern Paraguay there is one uranium deposit close to the town of Yuty, and drilling indicates elongated, uranium-bearing roll fronts. At least one other area with good potential to become a new uranium district, located north-east of the city of Coronel Oviedo, is under investigation.

Additional uranium potential in eastern Paraguay is also likely to exist in Upper Permian sandstone near the town of Curuguaty and within Silurian sandstone sequences east of the village of Eusebio Ayala.

Recent and ongoing uranium exploration and mining development activities

In the 2019-2021 period, exploration activities were focused on the Coronel Oviedo area. Several radon emmanometry surveys and drilling exploration totalling approximately 1 000 m were carried out. Total operating expenditures for the whole period are estimated at USD 750 000.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

UEC has reported about 4 290 in situ tU conventional resources, as regulated by Canadian Securities Administrators (CSA) National Instrument 43-101, from the Yuty Project. These are made of reasonably assured resources worth 3 430 tU at a grade of 0.044% U, and inferred resources worth 860 tU at a grade of 0.04% U.

The resource estimate is based on the development of a three dimensional geologic and resource model, using mainly the results of 256 drill holes totalling 31 000 metres of core and rotary drilling carried out between 2007 and 2011. Additionally, some 75 000 metres of drilling had been completed from 1976 to 1983.

Pumping testing indicates that the uranium-bearing unit has aquifer characteristics that would support operational rates for ISL mining and that the aquifer properties determined from the test fall within the range of values determined at other uranium ISL projects located in the United States in situ recovery (ISR) provinces. Metallurgical test work indicates that a satisfactory rate of extraction can be obtained using a sulphuric acid lixiviant.

Adjacent to Yuty, UrAmerica owns the Parana Basin Project, an extensive area of uranium mineralisation with several detected uranium anomalies and inferred resources of 770 tU. This estimate is based on extensive regional exploration work and reconnaissance scale drilling by UrAmerica’s predecessor, Wildhorse Explorations S.A., the Paraguayan branch of Wildhorse Energy Ltd.

Updated in situ uranium identified resources total 5 060 tU in the production cost category <USD 130/kg.

Undiscovered conventional resources (prognosticated and speculative)

UEC has reported an NI 43-101 exploration target at Coronel Oviedo ranging from 8 900 to 21 500 tU at grades between 0.034 and 0.044% U, which can be categorised as prognosticated resources.

Estimates are based on a 10 000-metre drilling programme completed by UEC in 2012. A total of 35 holes were drilled, averaging 290 metres in depth.

Aquifer testing to date indicates that the uranium-bearing unit has aquifer characteristics that would support operational rates for ISL mining and that the aquifer properties determined from the test fall within the range of values determined at other uranium ISL projects located in Wyoming, Texas and Nebraska. Determination of amenability to acid and alkaline leaching is still pending.

Uranium production

There has been no past production of uranium.

Uranium exploration and development expenditures and drilling effort – domestic

(USD)

	2018	2019**	2020**	2021** (expected)
Private* exploration expenditures	0	250 000	250 000	250 000
Total expenditures	0	250 000	250 000	250 000
Private* exploration drilling (m)	0	330	330	330
Total drilling (m)	0	330	330	330

* Non-government.

**Average estimated figures have been considered.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)*
In situ leaching acid	0	0	3 430	3 430	86
Total	0	0	3 430	3 430	86

* Based on column leaching test (NI 43-101 report).

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)*
In situ leaching acid	0	0	3 430	3 430	86
Total	0	0	3 430	3 430	86

* Based on column leaching test (NI 43-101 report).

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	3 430	3 430
Total	0	0	3 430	3 430

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)*
In situ leaching acid	0	0	1 630	1 630	86
Total	0	0	1 630	1 630	86

* Based on column leaching test (NI 43-101 report).

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery facor (%)*
In situ leaching acid	0	0	1 630	1 630	86
Total	0	0	1 630	1 630	86

* Based on column leaching test (NI 43-101 report).

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	1 630	1 630
Total	0	0	1 630	1 630

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	8 900-21 500	8 900-21 500

Peru

Uranium exploration and mining development

Historical review

Historically, Macusani, in the Department of Puno in south-eastern Peru, has been the most important uranium district, with uraniferous mineralisation found in acid volcanic Mio-Pliocene rocks.

Original radiometric prospecting revealed over 40 uraniferous areas; the most important of them are Chapi, Chilcuno-VI, "Pinocho", Cerro Concharrumio and Cerro Calvario.

Deposits are hosted almost entirely by the Upper Miocene Macusani Formation, about 500 m in thickness, a gently dipping succession of subaerial, exceptionally reduced, peraluminous sillimanite-andalusite-muscovite-biotite rhyolites that, through crystal fractionation, were intensely enriched in alkali (Li, Rb, Cs) and lithophile metals (Sn, W, Nb, Ta, Be), as well as in F, B and P. Rhyolites lack ash flow petrographic features and were erupted as crystal-charged frothy debris-flows, with the absence of explosive degassing permitting the exceptional retention of ore metals.

Background (whole rock) uranium contents of the younger lava flows average 28 ppm U (0.003% U) and attain 120 ppm U (0.012% U) and 270 ppm U (0.027% U) in coeval hypabyssal intrusions and residual glasses (obsidian), respectively.

Considering all the surveyed areas, Chapi was selected as the most important site, and detailed radiometry, emanometry, trenching and gallery work, as well as diamond drilling, were carried out. The mineralisation is in sub-vertical fractures distributed in structural lineaments from 15 m to 150 m in width and 20 m to 30 m in thickness. Grades vary between 0.03% U and 0.75% U, with an average of 0.1% U. Therefore, based on the available geological and exploration results, a minimum potential of 10 000 tU was assigned to the Chapi site and 30 000 tU to the whole Macusani uraniferous district.

Since 2003, private companies restarted exploration in both the Macusani district and the Santa Lucia-Rio Blanco and Pampacolca areas (250 km from Macusani near Arequipa, in the south of Peru), which are also located in a Tertiary volcanic environment. In addition, the Peruvian Nuclear Energy Institute (IPEN), through its promotional activities, proposed highlighting new areas of interest such as the San Ramón Oxapampa and Corongo areas in the central region of the country, where some work had been conducted to identify potential uraniferous regions.

Further studies on mineralisation in the Macusani district indicated that uranium mineralisation is cropping out at elevations between 4 100 m and 4 400 m around the Quenamari Plateau, west-northwest of Macusani. It comprises stockworks and associated disseminations of two coarse-grained yellow minerals, meta-autunite (hydrous calcium-uranyl phosphate) and subordinately, weeksite (hydrous potassium-uranyl silicate). From a mining standpoint, mineralised zones are made of manto, but are neither strictly stratiform nor stratabound. There is no evidence for precursor uraninite/pitchblende occurrence and the ore's thorium content is negligible.

Several companies have focused on Macusani in an effort to further develop uranium resources through drilling different prospects in the district.

Between 2010 and 2013, resource estimates by the Mineral Corporation for different complexes of the Macusani district were reported.

As uranium potential in other parts of Peru is considered important, IPEN proposed to highlight other areas of potential interest. In 2012, IPEN subsequently discovered new uranium occurrences in the San Ramón Oxapampa region, where initial results had demonstrated important uranium potential.

In 2015, Plateau Uranium Inc. reported an NI 43-101 compliant resource estimate for the Kihitian, Isivilla and Corani uranium complexes in the Puno district.

In 2016, an NI 43-103 preliminary economic assessment (PEA) of the Macusani project was prepared for Plateau Energy Metals. According to that report, Macusani was able to produce uranium at a cost of USD 38/kg U, when the international spot price for uranium was USD 66/kg U. The nominated base case called for the potential economic material resource of 109 Mt of ore with an average grade of 245 ppm U (0.02% U) to be mined over 10 years at 10.9 Mt/a with average annual production of 2 340 tU.

Summing up the private interest, there have been several mining companies that have explored for uranium in the Puno, Arequipa and Junín regions, including Peruvian companies Minera Milpo and Macusani Yellowcake, Canadian companies Vena Resources, Cardero Resources, Solex Resources, Frontier Pacific Mining, Wealth Minerals, Strathmore Minerals and Plateau Energy Metals, and Australian companies Range Resources-Contact Uranium and Alara Uranium.

Recent and ongoing uranium exploration and mining development activities

The Macusani district continues to be the focus of uranium exploration activities in Peru. Uraniferous mineralisation in Macusani is hosted by young rhyolites of Upper Miocene age (8-6 Ma), where there are more than 70 radiometric anomalies depicted to date on the Macusani plateau, of which around 20 have been drilled.

In 2021, American Lithium Corp. acquired Plateau Energy Metals and its projects in the Macusani district. In addition to holding several uranium deposits after this acquisition, American Lithium discovered three new anomalies and analyses of grab samples that led to the determination of an average uranium content of 18 270 ppm U (1.8% U).

Based on positive results from prospecting, mapping and sampling, American Lithium announced updated drilling plans (12 000 m; 70 holes) for the Macusani project to expand existing uranium resources and identify new deposits. The permitting process has been initiated, including development of an environmental impact assessment and community access agreements. Drilling is expected to start once an exploration permit is granted.

In addition, Azincourt Energy Corp. (Canada) reported interest in intensifying exploration activities at the Escalera Group uranium-lithium project located on the Picotani Plateau in south-eastern Peru. The Escalera Group consists of three concessions (Lituania, Condorlit, Escalera) acquired by the company in 2020, covering a combined area of 7 400 hectares of prospective exploration targets for volcanic-hosted supergene/surficial uranium and lithium. Surface rock samples obtained in 2017-2018 from the Escalera project returned values of up to 3 560 ppm U (0.36% U) and 153 ppm Li, while historical samples have yielded values up to 6 812 ppm U (0.68% U).

Finally, Fission 3.0 Corp. (Canada) holds the rights to 9 claim blocks encompassing 5 100 ha, and surface rights over some of the areas with known uranium mineralisation. In 2016, the potential of these properties was demonstrated by a drilling programme that resulted in 13 of 16 holes striking mineralisation, with high-grade uranium values of up to 12 151 ppm U (1.2% U) over 0.5 m only 16 m from surface, and lithium of up to 533 ppm over 0.5 m.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

According to the NI 43-101 report originally prepared for Plateau Energy Metals, the identified conventional resources of the Macusani district total approximately 47 710 in situ tU, comprised of 19 970 tU reasonably assured resources and 27 740 tU inferred resources. Since 2021 the Macusani project is under the control of American Lithium.

Identified conventional resources of Macusani district

(in situ tonnes U)

Prospect	RAR	IR	Total
Corachapi	1 930	730	2 660
Chilcuno	7 610	9 120	16 730
Quebrada Blanca	1 540	3 620	5 160
Tantamaco	1 410	6 150	7 560
Isivilla	1 350	2 180	3 530
Colibri II-III	5 650	1 580	7 230
Nuevo Corani	480	680	1 160
Tuturumani	0	480	480
Calvario I-Real	0	550	550
Puncopata	0	1 280	1 280
Tupurumani	0	1 370	1 370
Total	19 970	27 740	47 710

Undiscovered conventional resources (prognosticated and speculative resources)

Prognosticated conventional resources account for approximately 19 780 tU and occur in the following sectors of Macusani: Kihitian (10 440 tU), Tupurumani (5 600 tU), Corachapi (1 910 tU), Isivilla (1 330 tU) and Corani (500 tU).

In addition, there are some 45 360 tU of speculative resources, according to the information by private companies involved in uranium exploration projects in the Macusani district, notably American Lithium and Fission 3.0. As a result, speculative resource values have been updated from the amounts reported in Red Book 2018.

Unconventional resources and other materials

Unconventional resources account for a minimum of 41 600 tU, which include phosphates, granites with high uranium content and hydrothermal deposits.

Unconventional resources

(in situ tonnes U)

Permo-triasic granites*	20 000 tU
Bayóvar phosphates**	16 000 tU
Thirty-nine locations***	5 600 tU
Total	41 600 tU

* Granites with radioactive anomalies and uranium occurrences located in the departments of Junín and Pasco, average 50-80 ppm U (0.005-0.008% U).

** Currently, only exploited rock phosphate concentrate; the evaluated content is 46 ppm U (0.005%U).

*** Others in the rest of the country, uranium deposits associated with hydrothermal deposits (Cu Pb-Ni-W).

In 2010, the Vale company (formerly Vale do Rio Doce) of Brazil started exploitation of the Bayóvar phosphate deposit through its local subsidiary, Miski Mayo SRL. Before the start of the operation, the company planned for the possibility of uranium recovery during phosphate production, but these plans have not yet been implemented.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Mining activities, formerly conducted by the government, entered a privatisation process in 1992 with the application of the Mining Investment Promotion Law. This legislation aims to provide stability and a guaranteed framework for long-term investments in mining, including uranium. In recent years, the reactivation of interest in uranium exploration has resulted in allowing several foreign private companies to conduct exploration and evaluation programmes.

The Peruvian state, by promoting investment in uranium mining, plans to evaluate the potential for uranium in the entire country.

The Law 28 028 regulates the use of ionising radiation sources (2003), while the nuclear regulatory body is the Peruvian Nuclear Energy Institute (IPEN).

Complementary regulations issued by IPEN are:

- Regulation of Radiological Safety (1997), based on IAEA International Basic Safety Standard No. 115;
- Regulation of Physical Protection for Nuclear Facilities and Materials (2002);
- Regulation of Law 28 028 (2008), which refers to the authorisations for different nuclear and radiological practices.

Peru does not yet have any specific regulations for uranium mining, but IPEN is working with the support of the IAEA on the development of a regulatory framework for this purpose. Under this initiative, mandatory technical standards and regulatory guides to inform applicants are being prepared.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Open-pit mining (OP)	0	19 970	19 970	19 970
Total	0	19 970	19 970	19 970

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Heap leaching* from OP	0	19 970	19 970	19 970
Total	0	19 970	19 970	19 970

*A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Volcanic-related	0	19 970	19 970	19 970
Total	0	19 970	19 970	19 970

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Open-pit mining (OP)	0	27 740	27 740	27 740
Total	0	27 740	27 740	27 740

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Heap leaching* from OP	0	27 740	27 740	27 740
Total	0	27 740	27 740	27 740

*A subset of open-pit and underground mining, since it is used in conjunction with them.

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Volcanic-related	0	27 740	27 740	27 740
Total	0	27 740	27 740	27 740

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
6 610	19 780	19 780

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
45 360	45 360	0

Poland*

Uranium exploration and mine development

Historical review

Prospecting for uranium concentration in Poland began in 1948. An industrial plant in Kowary (Lower-Silesian Voivodeship) was established for the exploitation and processing of uranium from local deposits.

Research beginning in 1956 by the Polish Geological Institute involved the exploration of Carboniferous formations of the Upper Silesian Coal Basin, phosphorite formations and research in boreholes in the Polish Lowlands. As a result of this research, signs of uranium mineralisation were discovered in lower Ordovician formations of the Podlasie Depression (the "Rajsk" deposit) and in Triassic formations of the Perybaltic Syneclize and the Sudetes (Okrzeszyn, Grzmiąca, Wambierzyce). Approximately 20 tU were extracted from the Kopaliny-Kletno deposit.

In the Ladek and Snieznik Klodzki metamorphic formations, small occurrences of uranium mineralisation were discovered, including the Kopaliny-Kletno deposit.

Recent and ongoing uranium exploration and mine development activities

There are no current (up-to-date) uranium deposits documented in Poland. However, there are some prospective indications of uranium and currently some small prospects amenable for the discovery of uranium that could potentially be economically exploited.

In 2014, Poland completed geological and technological analyses and modelling of a process for uranium extraction from low-grade Ordovician Dictyonema shale (black shale-type). Analysis has shown that the costs of obtaining raw material required to produce 1 kg of uranium would be several times higher than the uranium market price at that time. In addition, resources of uranium in waste heaps from prospecting and extractive operations in the Sudety Mountains in the years 1948-1967 are estimated at 10 to 30 tU. Since 2015, geological exploration of uranium ore has not been conducted in Poland.

In 2017 and 2018, the first analysis of potential unconventional uranium resources was prepared in Poland.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

The data presented in the table below summarises information from historic geological documentation that does not fulfil current requirements for resource reporting and the potential for mining under current economic conditions. Reinterpretation of geological data in 2009-2010 showed that Poland has no identified conventional uranium resources that could be mined under current market conditions. Modelling of uranium extraction by underground mining from the Rajsk deposit related to the low-grade Ordovician Dictyonema shales (black shale-type) showed

* Report based on Red Book 2016 publication, updates from Poland and the NEA Nuclear Energy Data (Brown Book) 2020.

that the costs of obtaining raw material to produce 1 kg of uranium would be far too high. A comparison of these costs with market prices from the last 30 years implies that the extraction of uranium from those rocks will remain uneconomic for the foreseeable future.

Identified conventional resources*

(in situ tonnes U)

Region	Resources	Uranium content (%)
Rajsk deposit (Podlasie Depression)	5 320	0.025
Okrzeszyn (Sudetes)	937.6	0.05-0.11
Grzmiąca (Sudetes)	792	0.05
Wambierzyce (Sudetes)	217.5	0.0236

* Note: These data represent historical geological resources that were reinterpreted in 2009-2010 and under present-day market conditions are subeconomic.

No other current reasonably assured and inferred uranium resource statistics are available.

Undiscovered conventional resources (prognosticated and speculative resources)

Historical research also led to the identification of 20 000 tU of speculative resources. However, as with the identification of uranium occurrences noted above, the speculative resource estimate requires modern methods to confirm results.

Speculative conventional resources

(in situ tonnes U)

Region	Resources for depth to 1 000 m
Perybaltic Syneclise	20 000

No other current prognosticated and speculative uranium resources estimates are available.

Uranium production

Historical review

In 1948, a government-operated industrial plant was established in Kowary (Lower Silesia) to process ore mined from local uranium deposits. Exploitation of vein deposits in the Karkonosze-Izera Block and metamorphic deposits in the Ladek and Snieznik Klodzki Blocks continued until 1967. Total production amounted to 541.8 tU from deposits presented below.

Exploitation of vein deposits in the Karkonosze-Izera Block (Wolnosc, Miedzianka, Podgorze, Rubezal, Mniszkow, Wiktoria, Majewo, Wolowa Gora, Radoniów, Wojcieszyce) and of metamorphic deposits in the Ladek and Snieznik Klodzki Blocks (where some small uranium occurrences and the Kopaliny-Kletno deposit were discovered) took place until 1967, at which time the deposits were almost completely depleted.

During this period, all uranium produced was exported to the former Soviet Union. It is estimated that between 1948 and 1967 approximately 650 tU were mined in the Sudetes (southwest Poland). Chemical treatment of low-grade ores started in Kowary in 1969 and continued until 1972, producing a significant volume of waste that was left in a tailings pond.

Historical uranium production for selected deposits

(tonnes U)

Deposit name*	Initial resources**	Produced***
Wolnosc	94.0	94.0
Miedzianka	14.7	14.7
Podgorze	280.0	199.0
Rubezal	0.5	0.5
Mniszkow	4.5	4.5
Wiktoria	0.3	0.3
Wolowa Gora	2.5	2.5
Radoniów	345.0	214.0
Wojcieszyce	14.4	12.3
TOTAL	755.9	541.8

* Note: These are a subset of vein deposits from a larger group of deposits listed below.

** Resources not specified as either recoverable or in situ.

*** Production not specified, but assumed to be from concentrates.

Status of production capability and recent and ongoing activities

There is currently no uranium production in Poland and there are no plans for future production.

Environmental activities and socio-cultural issues

All exploitation activities associated with uranium mining and processing in Poland were performed between 1948 and 1976. Although the companies associated with this activity no longer exist, there remains a need to remediate the environment in the area around the sites where the mines operated. The Geological and Mining Law stipulates that the State Treasury is accountable for liabilities from all past uranium production activities in Poland. Therefore, the government is responsible for funding the remediation, using either the national or the district Environmental Protection Fund.

The regional authorities of the voivodship (local administration area) and its special inspectorates or officers are responsible for different aspects of the remediation. The local authorities approve remediation plans and supervise their execution and impacts. The inspectorates of the Environmental Protection of a particular voivodship are responsible, in general, for environmental monitoring. Radiological monitoring is considered a part of this overall monitoring effort and it is being performed under the responsibility of the President of the National Atomic Energy Agency.

Since 1996, Poland has taken part in the PHARE Multi-country Environmental Sector Programme on “Remediation Concepts for the Uranium Mining Operations in Central and Eastern European Countries” (CEEC). PHARE stands for the Poland and Hungary Assistance for the Restructuring of the Economy, an initiative of the European Union. In the framework of this programme, an inventory and a common database for the CEEC have been created. According to this inventory, the situation in Poland is characterised by a large number of small-scale liabilities from uranium exploration, localised over several places in the country and generally causing minor environmental impacts.

Only a limited number of issues related to mining and milling are considered to be causing serious impacts and the most important is the tailings pond in Kowary. The 1.3 ha hydrological construction is closed on three sides by a dam that has been modified a number of times. The dam itself is 300 m long (the sum of three sides) and has a maximum height of 12 m. As a result of uranium processing activities, the tailings pond has been filled with about 250 000 tonnes of fine-grained gneisses and schists with average uranium content of 30 ppm (0.003% U). In the early 1970s, the Wroclaw University of Technology (WUT) received, by governmental decision, the ownership of both the area and the facilities of the former uranium mining company. Subsequently, a company owned by the WUT has continued to use the existing chemical plant for various experimental processes on rare earth metals, chemical production and galvanic processes. As a result, about 300 tonnes of remnants of rare earth metal processing and 5 000 m^3 of post-galvanic fluids, with up to 30 tonnes of solids with a high content of aluminium, nickel, zinc and sodium sulphates, have been deposited in the pond.

The remediation programme of the tailings pond was prepared in 1997 by the WUT and successfully carried out under the PHARE programme until 2003. The specific objectives of this programme are related to the construction of drainage systems, the design and construction of the tailings pond cover and the final site reclamation.

Three abandoned uranium mines in the Sudetes Mountains of southwest Poland have been successfully adapted for use as tourist attractions and for educational purposes.

The National Atomic Energy Agency conducts regular monitoring of radiation. The monitoring covers the area degraded by extraction and processing of uranium ore in the Lower Silesia region. The monitoring programme consists of the following measurements:

- Total alpha and beta radioactivity in surface waters and groundwater.

  The water is sampled from the natural outflow of the former uranium mine workings, including surface watercourses and reservoirs, dug wells and natural springs discharge (a total of 30 sampling points).

- Total alpha and beta radioactivity in drinking water.

  The water is sampled from the surface and underground public drinking water intakes (a total of 37 sampling points).

- The level of gamma radiation on the surface.

  The measurements of gamma dose rate in the area of former mine workings: drifts, shafts, dumps and in their immediate surroundings (a total of 62 objects).

- Radon concentration in the atmosphere.

  The instantaneous radon Rn-222 concentration measurements (radon emanation) in the atmosphere in the open mine workings such as shafts and tunnels (a total of 22 objects).

- Radon concentration in water.

  The water is sampled from public drinking water intakes, natural outflow from former mine workings, springs and dug wells (a total of 58 objects).

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

In 2014, the Polish government introduced nuclear into the energy mix and the Council of Ministers adopted the Polish Nuclear Energy Programme. One of the topics covered is the potential mining of domestic uranium resources.

In 2020, the Council of Ministers approved an update of the Polish Nuclear Energy Programme. It reaffirmed the strategic plan of introducing the first nuclear power reactor with a capacity of 1.0 to 1.5 GWe by 2033 and 5 subsequent blocks every 2-3 years. As a result, it is expected that 6 reactors with a combined capacity of 6-9 GWe will be built in Poland. In terms of the institutional framework, there has been a substantial change as the Ministry of Energy was dissolved and its policy making competences have been transferred to the newly created Ministry of Climate, which is now in charge of both energy and climate protection policies.

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining	0	0	0	0	0
Underground mining	650	0	0	650	0
In situ leaching	0	0	0	0	0
Co-product/by-product	0	0	0	0	0
Total	650	0	0	650	0

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Granite-related	435	0	0	435	0
Metamorphite	215	0	0	215	0
Total	650	0	0	650	0

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
0	0	0	0	0	0	1 000	3 000	3 000	9 000

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
0	0	0	0	0	0	160	480	480	1 080

Portugal

Uranium exploration and mine development

Historical review

There has been no exploration and exploitation of uranium in Portugal since 2001, although unexploited uranium deposits exist in the southern part of the country.

In 2001, the Portuguese government launched decree law nº 198A/2001, which granted the state-owned mining company Empresa de Desenvolvimento Mineiro, S.A. (EDM) the concession for environmental rehabilitation of all abandoned and legacy mines (uranium and polymetallic). Since then, activities undertaken by EDM have prioritised safety and the environmental rehabilitation and remediation of legacy uranium mining sites.

Recent and ongoing uranium exploration and mine development activities

There has been no activity at home or abroad.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As previously reported (since the 2007 edition of the Red Book), Portugal hosts an estimated 4 500 tU of reasonably assured resources at production cost <USD 80/kgU and 6 000 tU reasonably assured resources in situ at production cost <USD 130/kgU. Additionally, 1 000 tU are reported as in situ inferred resources at production cost <USD 130/kgU. No processing or mining losses recovery factors have been applied to resource categories.

Undiscovered conventional resources (prognosticated and speculative resources)

As previously reported (since the 2007 edition of the Red Book), undiscovered conventional resources are estimated to include 1 500 tU of prognosticated resources. Speculative resources are not reported because only one outdated appraisal is available.

Uranium production

Historical review

Portugal's granite-related uranium deposits, located in the north-central area of the country, have been exploited from the beginning of the 20th century to 2001. Most of the uranium concentrates produced were exported.

In 1950-1951, a uranium mill facility processing 50 000 t/yr was built at Urgeiriça, and underground extraction continued until 1973, followed by in-place leaching from 1970 to 1991. The mine reached a depth of about 500 m and 1 600 m in length.

Between 1951 and 1962, Companhia Portuguesa de Radio (CPR) produced a total of 1 123 tU from 22 concessions, of which 1 058 tU were milled at the Urgeiriça plant and 65 tU at other mines by heap leaching. A low-grade concentrate was obtained by precipitation using magnesium oxide.

During the period 1962 to 1977, Junta de Energia Nuclear (JEN) took over the mining and milling activities from CPR, introducing organic solvent extraction in 1967 and expanding ore treatment capacity to 100 000 t/y to produce a rich ammonium uranate concentrate. In July 1985, a new capacity expansion to 200 000 t/yr was implemented. In all, 825 tU were produced under JEN management from the Urgeiriça plant and the pilot plant at Senhora das Fontes. Between 1977 and 2001, Empresa Nacional de Uranio, SA (ENU) produced 1 772 tU.

Of the total historical concentrate production, 25% came from the Urgeiriça mine. The Urgeiriça mill stopped conventional ore processing in 1999 and was decommissioned in March 2001. In this interim period, only charged ion-exchange resins from heap and in-place leaching plants, located in Bica and Quinta do Bispo mines, were processed at the Urgeiriça plant for yellowcake production. Nationally, 57 ore bodies have been mined, 29 by underground methods, 24 by open pit, and 4 by mixed underground/open-pit methods. In 18 of these mines, local ore treatment was used, but only at Urgeiriça were uranium concentrates produced at an industrial scale. Two pilot treatment plants (Forte Velho and Senhora das Fontes) produced limited amounts of concentrates (sodium uranate).

Ownership of the Urgeiriça mill plant evolved over its operational history and after CPR concluded the agreement with the Portuguese government in 1962, JEN took over until 1977 when ENU, a publicly-owned enterprise, acquired exclusive rights to uranium concentrate production and sales. In 1978, JEN exploration teams joined the Direccao-Geral de Geologia e Minas. In 1992, ENU was integrated into the Portuguese state-owned mining company EDM. In March 2001, EDM decided to liquidate ENU by the end of 2004.

Status of production facilities, production capability, recent and ongoing activities and other issues

Rehabilitation and remediation (environment and safety) are the only activities currently being developed by EDM.

Future production centres

No future production centres are planned.

Environmental activities and socio-cultural issues

EDM was granted the concession by the Portuguese government to deal with mining legacy sites, including remediation work at several uranium legacy sites. This work on legacy uranium and radium mine sites required expenditures of more than EUR 52.6 million (USD 62.5 million) between 2001 and 2015. An additional investment of EUR 35 million (USD 41.65 million) was spent between 2016 and 2020.

As of 2020, the uranium mining and milling sites that had been or were being remediated included the Urgeiriça, Bica, Cunha Baixa, Rosmaneira, Mondego Sul, Vale da Abrutiga, Barroco, Freixiosa, Prado Velho, Castelejo, Mortórios, Ribeira do Bôco, Canto do Lagar and Quinta do Bispo (1st phase) mine sites.

Uranium requirements

Portugal has no uranium requirements.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The recently published Ministerial Council Resolution No. 107/2019 approved the Roadmap for Carbon Neutrality 2050 (RNC 2050), adopting the commitment to achieve carbon neutrality in Portugal by 2050. Nuclear energy is not considered in Portugal's energy mix. A new energy strategy, Energia 2020, reaffirms the importance of renewable sources (mainly wind, solar and hydropower) and increased efficiency to reduce external energy dependence and its associated impact on the trade balance and to meet commitments made under the Kyoto Protocol.

Uranium stocks

There have been no changes of stocks since the 2007 edition of the Red Book.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	500	500	NA
Open-pit mining (OP)	0	4 500	5 500	5 500	NA
Total	0	4 500	6 000	6 000	

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	500	500	NA
Conventional from OP	0	4 500	5 500	5 500	NA
Total	0	4 500	6 000	6 000	

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	4 500	6 000	6 000
Total	0	4 500	6 000	6 000

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	1 000	1 000	NA
Total	0	0	1 000	1 000	

Inferred conventional resources by processing method
(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	1 000	1 000	NA
Total	0	0	1 000	1 000	

Inferred conventional resources by deposit type
(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	1 000	1 000
Total	0	0	1 000	1 000

Prognosticated conventional resources
(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
1 000	1 500	1 500

Historical uranium production by production method
(tonnes U in concentrate)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining*	1 810	0	0	1 810	0
Underground mining*	1 326	0	0	1 326	0
Unspecified	584	0	0	584	0
Total	3 720	0	0	3 720	0

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method
(tonnes U in concentrate)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	3 136	0	0	3 136	0
In-place leaching*	250	0	0	250	0
Heap leaching**	321	0	0	321	0
Other methods***	13	0	0	13	0
Total	3 720	0	0	3 720	0

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

*** Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Granite-related	3 720	0	0	3 720	0
Total	3 720	0	0	3 720	0

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrate	Enriched uranium stocks	Depleted uranium stocks	Reprocessed uranium stocks	Total
Government	168	0	0	0	168
Producer	0	0	0	0	0
Utility	0	0	0	0	0
Total	168	0	0	0	168

Russia

Uranium exploration and mine development

Historical review

Since the beginning of uranium exploration in Russia in 1944, more than 100 uranium deposits have been discovered in 14 districts. The most significant deposits are located in four uranium-bearing districts:

- the Streltsovsk district, which includes 19 volcanic, caldera-related deposits where underground mining of some deposits is ongoing;
- the Trans-Ural and Vitim districts, where basal-channel sandstone-type deposits are being developed for uranium production by in situ leaching (ISL);
- the Elkon district, which contains large metasomatite-type deposits prospective for future mining.

Recent and ongoing uranium exploration activities

There are two types of uranium exploration activities in Russia. One involves early-stage prospecting aimed at new deposit discovery and preliminary evaluation, and the second involves additional, more detailed exploration of earlier discovered deposits to improve resource estimates and delineate new resources.

Uranium prospecting

Uranium prospecting is financed by the federal budget of Russia through the Federal Agency for Mineral Resources (Rosnedra). In 2019-2020, the work was carried out mainly in the Siberian Federal District (Irkutsk and Novosibirsk Region) and in the Far Eastern Federal District (Republic of Buryatia, Trans-Baikal Region, Amur Region and Jewish Autonomous Region). The work focused on two main goals: expanding the resource base near existing uranium production centres and identifying large deposits in new regions suitable for development by ISL.

In 2019 and 2020, exploration was completed within the Ob area in Novosibirsk region, the Antasei area in the Vitim uranium ore district (Republic of Buryatia), and the Kuldur area of Khingan plateau (Amur Region, Jewish Autonomous Region). During this period, prospecting focused on the evaluation of surficial uranium deposits, and continued within the Vitim-Karenga area (Trans-Baikal Region). A processing flowsheet and technical report on resources will be developed based on exploration results.

As a result of exploration in the Shangulezh and Ermosokhin areas of the East-Sayan prospective region (Irkutsk Region) 2 200 tU of prognosticated (P1) and 5 500 tU of speculative (P2) resources related to unconformity-type mineralisation were identified.

Exploration of existing deposits

Exploration of identified deposits is carried out by subsidiary uranium mining enterprises of JSC Atomredmetzoloto (ARMZ), which is a part of the Russian State Atomic Energy Corporation Rosatom.

The main exploration activities in 2019 and 2020 were concentrated at the Dobrovolnoye deposit (Dalur mine). A significant increase in investment, from 112.3 million rubles in 2019 to 467.8 million rubles in 2020, is associated with the development of exploration drilling at the Dobrovolnoye deposit. The completion of exploration is planned for 2023. The Priargunsky production centre continued limited exploration focused on identifying uranium resources on the flanks of the deposits by drilling boreholes from underground mine workings.

Uranium exploration abroad

From 2018 to 2020, through Uranium One, owned by the State Atomic Energy Corporation Rosatom, Russia carried out exploration and pilot test work for uranium at joint ventures in Kazakhstan, work in Tanzania to prepare for the development of the Mkuju River uranium project, and exploration in Namibia.

In Kazakhstan, six uranium mines jointly owned by Uranium One are in commercial operation. In 2020, exploration in the expanded geological allotment of the Zarechnoye deposit was completed and additional resources were identified for the extension of the life of the mine. In 2021 a new exploration programme was launched at the Kharasan mine to convert resources into more reliable categories.

In Tanzania, Mantra Resources (purchased by ARMZ in 2011) completed major exploration of the Mkuju River deposit in 2016. During 2017-2019, further development was suspended due to unfavourable uranium market conditions. In 2020, a decision was made to build a pilot processing plant during 2021-2022 and to proceed with pilot open-pit mining during 2023-2025.

In Namibia, Uranium One, through its subsidiary Headspring Investments Pty., conducted an intensive drilling exploration programme during 2019-2020. As a result, a new sandstone-type uranium deposit (Wings) was discovered with resources confirmed by a JORC compliant technical report amounting to: indicated reasonably assured resources (RAR) of 14 700 tU, inferred resources of 9 900 tU and an exploration potential of 40 000 tU. Based on 2020 results, resources are potentially amenable for development by ISL. A pre-feasibility study completed in 2021 has confirmed positive economics for the ISL mining method. The 2021 exploration programme includes further drilling aimed at identifying additional resources and preparing for an ISL pilot test.

Recent mine development activities

JSC Dalur (Kurgan Oblast) started preparation for pilot uranium mining at the Dobrovolnoye deposit in 2020.

In 2020, JSC Khiagda (Republic of Buryatia) started development at the Kolichikan deposit with 6 530 tU RAR and the Dybryn deposit with RAR of 6 634 tU. Kolichikan is planned for commercial mining in 2021 and Dybryn in 2023.

During 2019-2020, the Priargunsky production centre continued construction of the surface complex and infrastructure elements of new mine No. 6 with a design capacity of 2 300 tU/yr. It will support the development of the Argunskoye and Zherlovoye deposits. Commercial mining is scheduled to begin in 2026.

The development of deposits in the Elkon uranium region was suspended due to unfavourable market conditions.

Uranium resources

Identified resources (reasonably assured and inferred resources)

As of 1 January 2021, total recoverable uranium resources in Russia (RAR + inferred resources) amounted to 656 864 tU, while in situ known resources comprised 840 867 tU. Compared with the data as of 1 January 2019, this is a decrease of 5 065 tU in recoverable resources due to depletion of the resources by mining in 2019 and 2020.

Total recoverable RAR amounted to 251 852 tU (in situ 327 099tU), of which 82% are recoverable at a cost of <USD 130/kgU and 8% at <USD 80/kgU. With respect to RAR, 68% are planned to be developed by conventional underground mining methods. The majority in this group relates to metasomatic-type uranium deposits in the Elkon region. All resources in the cost category of <USD 80/kgU relate to the sandstone-type deposits that are planned to be developed by ISL.

Inferred recoverable uranium resources in Russia amounted to 405 012 tU (in situ 513 767 tU), of which less than 4% can be recovered at less than USD 80/kg. More than 70% of inferred resources are planned to be developed by underground mining from metasomatic and volcanic type deposits.

Undiscovered conventional resources (prognosticated and speculative resources)

In the Russian classification system, prognosticated resources relate to the P1 category and speculative resources relate to the P2 category. As of 1 January 2021, prognosticated (P1) resources in Russia amounted to 164 690 tU, of which 110 650 tU are in the cost category of <USD 130/kgU. Speculative (P2) resources amounted to 528 560 tU, of which 148 200 tU are categorised as <USD 130/kgU.

Compared with the data as of 1 January 2019, the prognosticated resources in the cost category of <USD 130/kgU are almost the same, while a small decrease occurred in the <USD 260/kgU category due to the lack of confirmation of resources based on recent geological survey data.

The main portion of the undiscovered uranium resources is located in the Trans-Baikal Region (the Urulyunguevsky and East-Trans-Baikal uranium ore regions), in the Irkutsk Region (Sayan region), and in the Republic of Buryatia (Vitim region).

Undiscovered resources categorised at <USD 130/kgU are dominated by sandstone-type deposits, and in the cost category of <USD 260/kgU, volcanic-related and unconformity-type deposits prevail. The main sandstone-type resources are concentrated in the Republic of Buryatia (the Vitim and South Vitim uranium ore regions), where P1 resources amount to 71 300 tU and P2 resources amount to 90 600 tU, accounting for 42% and 17% of all speculative resources of Russia, respectively. Resources related to unconformity and volcanic type mineralisation prevail in the Trans-Baikal Region and the Irkutsk region. Additional P1 resources (20 000 tU) associated with fishbone detritus (phosphate deposit type) are located in the Ergeninsky uranium region in the Republic of Kalmykia.

Uranium production

Historical review

As of 1 January 2021, cumulative uranium production in Russia amounted to 176 482 tU. Total production at the Priargunsky production centre amounted to 153 762 tU, making it the world's largest enterprise for aggregate production of uranium.

Status of productive capabilities

Uranium mining in Russia is carried out by three enterprises that are part of the uranium mining company Uranium Holding ARMZ (JSC Atomredmetzoloto). The annual uranium production in Russia in 2020 amounted to 2 846 tU, of which 1 240 tU were obtained by traditional underground mining and 1 606 tU by ISL.

The PJSC Priargunsky Industrial Mining and Chemical Union (PIMCU) remains the main uranium mining centre in Russia. The resource base for the enterprise includes the volcanic type uranium deposits of the Streltsovsk uranium ore region with recoverable resources of 75 336 tU (96 585 tU in situ) as of 1 January 2021.

Uranium mining was carried out at two underground mines (mine No. 1 and mine No. 8) and mined ore was processed either at a hydrometallurgical plant or heap leaching site. Of the 1 240 tU mined in 2020 by the underground method, 1 120 tU were produced at the hydrometallurgical plant and 120 tU were processed by heap leaching. During 2018-2020, construction of the mine No. 6 surface complex and infrastructure elements continued (design capacity of 2 300 tU/yr) for the development of the Argunskoye and Zherlovoye deposits. The start of mining is scheduled for 2026.

JSC Dalur in the Kurgan Oblast carries out the development of the Dalmatovskoye, Khokhlovskoye and Dobrovolnoye deposits by ISL to maintain a production capacity of 600 tU/yr. As of 1 January 2021, recoverable resources of the three deposits amounted to 9 543 tU (12 724 tU in situ). Uranium production in 2020 amounted to 585 tU. In 2020, the drilling of wells at the Dobrovolnoye deposit began for pilot ISL mining that started at the end of 2021.

JSC Khiagda carries out ISL uranium mining of deposits at the Khiagda ore field in the Republic of Buryatia with recoverable resources of 25 133 tU (33 510 tU in situ). In 2020, 1 021 tU were produced, which is 163 tU more than in 2018. In 2019, the development of the Istochnoye deposit began and research work was completed at the Kolichikan and Dybryn deposits. Development of the Kolichikan deposit is planned for 2021.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #2	Centre #3	Centre #4
Name of production centre	Priargunsky Mining Combine (Priargunsky)	Dalur	Khiagda	Elkon Mining and Metallurgical Complex (Elkon)
Production centre classification	Existing	Existing	Existing	Prospective
Date of first production	1968	2004	2010	NA
Source of ore:				
Deposit name(s)	Antei, Streltsovskoe and others	Dalmatovskoe, Khokhlovskoe, Dobrovolnoye	Khiagda, Vershinnoe and others	Yuzhnoe, Severnoe
Deposit type(s)	Volcanic	Sandstone basal channel	Sandstone basal channel	Metasomatic
Recoverable resources (tU)	75 336	9 543	25 133	303 600
Grade (% U)	0.16	0.04	0.05	0.15
Mining operation:				
Type (OP/UG/ISL)	UG, HL	ISL	ISL	UG
Size (tonnes ore/day)	6 700	NA	NA	5 500
Average mining recovery (%)	95	75	75	85
Processing plant:				
Acid/alkaline	Acid	Acid	Acid	Acid
Type (IX/SX)	IX	IX	IX	IX
Size (tonnes ore/day)	4 700	No data	No data	No data
Average process recovery (%)	95	98	98	95
Nominal production capacity (tU/year)	3 000	600	1 000	5 000
Plans for expansion	Mine #6	Dobrovolnoye dep.	Yes	No
Other remarks				

Employment in the uranium industry

In 2020, the number of employees working in the uranium industry amounted to 6 103, of which 5 048 were PIMCU employees, 481 were Dalur employees and 574 were Khiagda employees. Considering that a portion of PIMCU personnel is involved in general-purpose auxiliary and service facilities, the number of employees directly related to PIMCU uranium production amounted to 3 645.

Future production centres

Since 2017, the development of deposits in the Elkon and Trans-Baikal uranium ore regions was suspended due to unfavourable market conditions.

Uranium requirements

As of 1 January 2021, 11 nuclear power plants in Russia were comprised of 37 units with a total installed capacity of 29.3 GWe. In 2020, Russian nuclear power plants generated 201.2 TWhr of electricity, which amounted to 20.3% of the electricity produced in the country.

The current annual consumption of Russian nuclear power plants amounts to a uranium equivalent of about 5 100 tU. Uranium fuel requirements are supplied by uranium produced in Russia and Kazakhstan, from uranium stockpiles and secondary sources.

The development of nuclear energy and the construction of new power plants in Russia, in a "high" scenario, foresees installed capacity growing to 35.3 GWe by 2035 and proportional growth in uranium requirements to as much as 5 300 tU/yr. This assumes nuclear energy development based on new nuclear power generation technologies and takes into account the UN Sustainable Development Goals on the global climate agenda and global energy security. The "low" scenario assumes the development of nuclear power to replace capacity that is phased out due to technological resource exhaustion and to maintain current economic growth rates and electricity demand.

Uranium exploration and development expenditures and drilling effort – Government domestic

(RUB millions)

	2018	2019	2020	2021 (expected)
Rosatom* exploration expenditures	21	112	468	13
Rosnedra** exploration expenditures	365	442	326	218
Rosatom development expenditures	139	0	168	491
Rosnedra development expenditures	0	0	0	0
Total Government expenditures	525	554	962	722
Rosatom exploration drilling (m)	7 600	25 000	100 000	3 400
Rosatom exploration holes drilled	46	54	194	13
Rosnedra exploration drilling (m)	7 610	10 879	14 653	3 000
Rosnedra exploration holes drilled	72	75	75	25
Rosatom development drilling (m)	NA	NA	NA	NA
Rosatom development holes drilled	NA	NA	NA	NA
Rosnedra development drilling (m)	0	0	0	0
Rosnedra development holes drilled	0	0	0	0
Subtotal exploration drilling (m)	115 210	35 879	114 653	6 400
Subtotal exploration holes	118	129	269	38
Subtotal development drilling (m)	NA	NA	NA	NA
Subtotal development holes	NA	NA	NA	NA
Total Government drilling (m)	115 210	35 879	114 653	6 400
Total number of Government holes drilled	118	129	269	38

* Russian State Corporation Rosatom. In previous editions, these expenditures were attributed to industry.

** Rosnedra is the Federal Agency for Mineral Resources.

Uranium exploration and development expenditures (non-domestic)

(USD millions)

	2018	2019	2020	2021 (expected)
Industry exploration expenditures	0.0	0.00	0.00	0.00
Government* exploration expenditures	1.7	3.61	9.74	31.36
Industry development expenditures	0.0	0.00	0.00	0.00
Government* development expenditures	0.0	0.00	1.36	14.57
Total expenditures	1.7	3.61	11.10	45.93

* Russian State Corporation Rosatom. In previous reports, these expenditures were attributed to industry.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	171 382	171 382	85-90
In situ leaching acid	0	20 594	20 594	20 594	75
Co-product and by-product	0	0	0	45 424	65
Unspecified	0	0	14 452	14 452	75
Total	0	20 594	206 428	251 852	77

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	153 648	153 648	85
In situ leaching acid	0	20 594	20 594	20 594	75
In-place leaching*	0	0	516	516	70
Heap leaching** from UG	0	0	17 218	17 218	70
Unspecified	0	0	14 452	59 876	75
Total	0	20 594	206 428	251 852	77

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	20 594	20 594	20 594
Granite-related	0	0	1 550	1 550
Intrusive	0	0	0	45 424
Volcanic-related	0	0	70 984	70 984
Metasomatite	0	0	103 982	103 982
Phosphate*	0	0	9 318	9 318
Total	0	20 594	206 428	251 852

* Considered conventional resources because uranium is the main commodity of interest.

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	251 014	301 448	85-90
Open-pit mining (OP)	0	0	0	1 973	70
In situ leaching acid	0	14 372	14 372	22 723	75
Co-product and by-product	0	0	0	35 217	65
Unspecified	0	0	9 087	43 651	75
Total	0	14 372	274 473	405 012	79

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	242 522	290 281	85
In situ leaching acid	0	14 372	14 372	22 723	75
In-place leaching*	0	0	2 068	4 565	70
Heap leaching** from UG	0	0	6 425	6 602	70
Heap leaching** from OP	0	0	0	1 973	70
Unspecified	0	0	9 086	78 868	75
Total	0	14 372	274 473	405 012	79

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	14 372	14 372	51 201
Granite-related	0	0	2 686	5 689
Intrusive	0	0	0	34 701
Volcanic-related	0	0	29 036	42 683
Metasomatite	0	0	221 252	258 031
Phosphate*	0	0	7 127	12 707
Total	0	14 372	274 473	405 012

* Considered conventional resources because uranium is the main commodity of interest.

Prognosticated conventional resources

(in situ tonnes U)

Cost Ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	110 650	164 690

Speculative conventional resources

(in situ tonnes U)

Cost Ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
148 200	528 560	0

Historical uranium production by mining method

(tonnes U concentrate)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining	38 655	0	0	38 655	0
Underground mining	117 132	1 300	1 240	119 672	1 150
In situ leaching	14 938	1 611	1 606	18 155	1 485
Total	170 725	2 911	2 846	176 482	2 635

Historical uranium production by processing method

(tonnes U concentrate)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	151 222	1 173	1 120	153 515	1 030
In-place leaching*	241	0	0	241	0
Heap leaching**	4 324	127	120	4 571	120
In situ leaching	14 938	1 611	1 606	18 155	1 485
Total	170 725	2 911	2 846	176 482	2 635

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	14 938	1 611	1 606	18 155	1 485
Volcanic and caldera-related	155 787	1 300	1 240	158 327	1 150
Total	170 725	2 911	2 846	176 482	2 635

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
2 846	100%	0	0	0	0	0	0	2 846	100%

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres	6 263	6 163	6 103	6 179
Employment directly related to uranium production	4 601	4 726	4 700	4 740

Mid-term production projection (tonnes U/year)

2021	2022	2025	2030	2035	2040
2 600	2 500	2 700	4 100	3 500	2 400

Mid-term production capability

(tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
1 700	1 700	2 700	2 700	1 700	1 700	2 300	4 100

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
1 600	1 600	1 600	3 500	1 500	1 500	1 500	2 400

Net nuclear electricity generation

(TWh net)

	2019	2020
Nuclear electricity generated (TWh net)	194.8	201.2

Installed nuclear generating capacity to 2040

(GWe net)

2019	2020	2025		2030	
		Low	High	Low	High
30.3	29.3	29.8	29.8	30.7	30.7

2035		2040	
Low	High	Low	High
31.5	35.3	NA	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030	
		Low	High	Low	High
5 000	5 100	4 700	5 300	4 500	5 200

2035		2040	
Low	High	Low	High
4 400	5 300	4 300	5 400

Saudi Arabia

Uranium exploration and mine development

Historical review

Historical uranium exploration programmes were completed in Saudi Arabia from the 1960s to the 1990s by contracted foreign organisations including the United States Geological Survey (USGS) and Lockwood, leading to the identification of airborne radiometric anomalies. The USGS also studied the uranium potential of the Ghurayyah deposit that was known for its rare earth elements (REE), Nb, Ta and Zr contents. Tertiary Minerals Plc identified 385 Mt of niobium-tantalum bearing ore grading 0.0245% Ta_2O_5 at Ghurayyah. Minatome completed a multi-year uranium exploration programme (1979-1984) including the follow-up of airborne radiometric anomalies and the evaluation and drill testing of U and Th prospects.

The mining and metals processing sector in Saudi Arabia is expected to grow as the country pursues its Vision 2030 goal of having the mining sector contribute to the economy. The country is going through a large industrial and economic diversification that will grow resource-heavy manufacturing sectors such as industrial machinery, electrical equipment and automotive, leading to an increase in demand for metal and mineral products.

Recent and ongoing uranium exploration and mine development activities

Saudi Arabia initiated a strategic exploration programme for mineral resources including uranium. Several government entities were aligned and co-operated with well-known international institutions. From March 2017 to March 2019, the first phase of uranium (U) and thorium (Th) exploration was conducted, including the evaluation of nine designated areas (including 36 subareas) covering a total area of 27 000 km^2 across Saudi Arabia. Exploration targets included intrusive, volcanic, phosphate, calcrete and sandstone-hosted deposit types.

The project aim was to carry out general exploration and geological assessment, including the estimation of inferred resources for uranium at promising sites, according to the JORC standard. Geological, geochemical and geophysical surveys, as well as trenches were completed over the 36 subareas, and 9 subareas were tested by drilling (70 763 m in 1 467 holes). The cost of the exploration programme was USD 37 million.

The Ghurayyah, Jabal Sayid and Thaniyat Turayf subareas were selected for detailed exploration and the estimation of inferred resources. The next phase of exploration will include the continued exploration of uranium prospects, and the development of reasonably assured resources at select deposits.

Ghurayyah Deposit (intrusive type: plutonic, peralkaline granite complex subtype – U, Nb, Zr, REE, Ta + Th)

The Ghurayyah deposit is located in the north-western part of the Arabian Shield in Saudi Arabia. This polymetallic deposit is hosted in a sub-circular granite complex with an outcrop area of 0.27 km^2. Based on geological and geophysical surveys and the drill core results, the granite's size was increased to 0.89 km^2 in area. It is distributed along a north-west trending regional fault and extends approximately 1 100 m along strike with a maximum width of 1 100 m. The maximum U mineralisation depth is up to 500 m, and an audio-magnetotelluric survey showed that the depth of the granite could reach more than 1 000 m. The uranium-bearing minerals (including uranothorite) in the deposit are accessory minerals, which occur as fine-grained disseminations as well as along micro-fractures in the granitic rocks.

- Ghurayyah Deposit mineral resource estimation

The Ghurayyah deposit is a large polymetallic deposit containing inferred in situ resources of 424 million tonnes grading 116 ppm U, (0.012% U) at a cut-off grade of 100 ppm U (0.01% U), and 324 ppm ThO_2, 185 ppm Ta_2O_5, 2 486 ppm Nb_2O_5, 960 ppm Y_2O_3 and 7 511 ppm ZrO_2, with contained metal including 49 028 tU and 137 359 tonnes of ThO_2. The ThO_2, Ta_2O_5, Nb_2O_5, Y_2O_3 and ZrO_2 resource estimates were completed based on the uranium mineralisation modelling. The resource remains open at depth and on the periphery of the deposit.

Summary of the in situ inferred mineral resources in the Ghurayyah deposit, November 2019

(at a cut-off grade of 100 ppm U)

Classification	Tonnage	Grade (ppm)					
	(Mt)	tU	ThO_2	Ta_2O_5	Nb_2O_5	Y_2O_3	ZrO_2
Inferred	424	116	324	185	2 486	960	7 511

Contained Metal (t)					
tU	ThO_2	Ta_2O_5	Nb_2O_5	Y_2O_3	ZrO_2
49 028	137 359	78 194	1 053 260	406 699	3 182 232

Jabal Sayid prospect (intrusive type: plutonic, peralkaline granite complex subtype – U, Nb, Zr, REE, Ta + Th)

The Jabal Sayid U-Th prospect is in the central Arabian Shield about 320 km northeast of Jeddah and 150 km southeast of Medina, covering an area of 588 km^2. The prospect is characterised by a large, exposed, pegmatite-aplite mineralisation zone extending nearly 2 km in a northeast-east to southwest-west direction, with varying widths of more than 50 m in the centre to 5-10 m in both the easternmost and westernmost sections. The outcropping mineralisation zone is consistent with the high eU (> 300 ppm) and high eTh (> 1 000 ppm) radiometric anomalies revealed by ground gamma-ray spectrometric surveys, indicating a promising U-Th mineralisation potential. The mineralisation potential is supported by radon anomalies in the Quaternary cover area to the north of the main mineralisation zone. Besides U and Th (including uranothorite), the pegmatite-aplite is also enriched in rare earth elements (REE) including Nb, Ta and Zr. The geology and grade continuity of the outcropped mineralisation zone was well established by systematic trenching (200 m spacing), surface channel sampling (100 m spacing), and drilling (200 m × (160-200 m) spacing). The drilling results indicated that the mineralisation remains open to both depth, and along strike to the west, with a maximum extension along the dip direction of ~700 m and 400 m in the central and western parts of the mineralised zone, respectively.

- Jabal Sayid prospect mineral resource estimation

The uranium and thorium mineral resources in the Jabal Sayid U-Th prospect were estimated using the kriging method, with inferred in situ resources of 34 million tonnes grading 415 ppm U (0.042% U) for a total of 14 135 tU and 1 698 ppm Th (65 916 t ThO_2) reported at a cut-off grade of 300 ppm U (0.03% U). During the exploration programme, 48 drill holes totalling 17 259 m were completed at the Jabal Sayid U-Th prospect. The chemical assay results from a total of 5 847 samples, including 1 024 quality control samples, were used for the resource estimation. Two domains were delineated and estimated.

Summary of in situ Inferred Uranium and Thorium Resources for the Jabal Sayid U-Th prospect

(at a cut-off grade of 300 ppm U)

Category	Tonnage	Average grade	Metal	
	(Mt)	U (ppm) Th (ppm)	tU	U_3O_8 (t) Th (t) ThO_2 (t)
Inferred	34	415 1 698	14 135	16 679 57 821 65 916

Thaniyat Turayf prospect (phosphate type)

The phosphorite deposits within the sediments of the Sirhan-Turayf shelf in northern Saudi Arabia form part of the large North African Middle East Tethyan phosphate province, which stretches from Morocco to Iraq. The Thaniyat phosphorite member at the base of the Jalamid Formation of the late Cretaceous (Campanian) to Palaeocene age, was deposited in a shallow marine shelf to intertidal zone. The uraniferous phosphorite layer extends continuously within a target area of about 70 km^2 and has an average thickness of 1.8 m, with an average density of 2.0 g/cm^3. The inferred in situ resources are estimated at 14 551 tU.

Inferred mineral resources in the Thaniyat prospect

(at cut-off grade of 50 ppm U)

Category	Tonnage (Mt)	Average grade		Uranium resources		Phosphate resources
		U_3O_8 (ppm)	P_2O_5 (%)	tU	tU_3O_8	tP_2O_5
Inferred	178	96	19.8	14 551	17 170	35 201 000

Identified conventional resources (reasonably assured and inferred resources)

Conventional resources have not been reported.

Undiscovered conventional resources (prognosticated and speculative resources)

Prognosticated undiscovered conventional resources have not been identified.

Unconventional resources and other materials

The uranium deposits and prospects in Saudi Arabia are reported as inferred unconventional resources including U resources associated with Nb, Zr, REE, Ta + Th, in peralkaline granite and pegmatite in the Ghurayyah and Jabal Sayid areas, and U associated with phosphate horizons. Total in situ unconventional uranium resources amount to 77 731 tU, including 63 171 tU associated with the intrusive plutonic deposit type and 14 560 tU associated with the phosphorite type.

Uranium production

Historical review

No uranium has been produced in Saudi Arabia.

Status of production facilities, production capability, recent and ongoing activities and other issues

No uranium has been produced in Saudi Arabia.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

Saudi Arabia has not produced or used mixed oxide fuels.

Production and/or use of re-enriched tails

Saudi Arabia currently does not have a uranium enrichment industry. Re-enriched tails have not been used or produced.

Production and/or use of reprocessed uranium

There is no production or use of reprocessed uranium.

National policies relating to uranium

The Saudi Nuclear Regulatory and Radiation Commission (NRRC) aims to regulate activities, practices and facilities involving the peaceful use of nuclear energy and ionising radiation; to control and ensure the safety and security of such use and compliance with nuclear safeguards; to protect humans and the environment against any actual or potential exposure to radiation, including exposure to natural radiation; and to implement Saudi Arabia's obligations under relevant treaties and conventions. The NRRC is a legal public organisation with financial and administrative autonomy. The Cabinet of Ministers issued a resolution that states that Saudi Arabia shall follow International Atomic Energy Agency safety standards as the minimum safety requirements.

Uranium requirements

Saudi Arabia is preparing to introduce the first nuclear power plant in the country. The nuclear power plant is expected to come into operation in the mid-2030s. This will introduce a demand for uranium in the next decade to fuel the nuclear power plant.

Supply and procurement strategy

The supply and procurement strategy for the planned nuclear power plants has not yet been decided.

Uranium exploration and development expenditures and drilling effort – domestic

(USD)

	2017	2018	2019	2020	2021 (expected)
Government exploration expenditures (USD)*	37 000 000				848 632
Total expenditures	37 000 000				NA
Government exploration drilling (metres)	70 763				0
Government exploration holes drilled	1 467				0
Government trenches (number)	967				0
Total drilling (metres)	70 763				NA
Total number of holes drilled	1 467				NA

* Exploration activities were carried out in the field from March 2017 to March 2019. Office based evaluation of information continued in 2020 and 2021.

Senegal

Historical review

There have been two important phases of uranium exploration in Senegal: 1) 1957 to 1965, when a general inventory of the uranium potential of Africa was undertaken, at which time the large deposits in Niger and Gabon were discovered, and 2) 1974 to present, which has been characterised by surveys focused on the Birimian Superior Precambrian sediments and secondary and tertiary basins with phosphate deposits. The collapse of uranium prices in the 1980s raised questions about the value of these focused surveys and the viability of uranium mineralisation in areas far inland and with no infrastructure, areas which could have been eliminated because of the limited chances of finding uranium concentrations large and rich enough to be economic.

1957-1965

The first work undertaken in Senegal by the French Atomic Energy Commission (CEA) from 1957 to 1961 was part of a systematic aerial survey of West Africa covering Senegal, Mali, Upper Volta and Niger. It was during these survey flights in 1960 that an aerial radiometric anomaly, Saraya, was identified at Kédougou (Southeast Senegal). Fourteen trenches were dug, and geochemical samples taken, which resulted in the identification of two types of anomalies: one in a fracture striking North 130° with yellow mineralisation and the other in a light-coloured syenite with calcite. Around the same time, ground verification of other airborne anomalies was undertaken, mainly by geochemical sampling and small research wells. Some geochemical anomalies were detected (the Dalafinn site, for example), which were usually associated with laterites. In 1961, the CEA made the decision to suspend the study of anomalies at Kédougou and nothing was undertaken in this area until work resumed in 1974.

In 1966, as part of a joint study between Mauritania and Senegal, CEA undertook a systematic radiometric study of the continental sedimentary basin of the Ferlo (northern Senegal) and along the bank of the Senegal River. This work, however, yielded no interesting results.

1974-present

On 29 May 1974, the Minister of Development of Senegal sent a letter to the General Administrator of the CEA, which later became the Compagnie Générale des Matières Nucléaires (COGEMA), requesting a resumption of uranium research. After a positive response, a research permit within East Senegal of 38 600 km² was awarded on 27 November 1974. From 1975 to 1976, studies focused on a series of Cambrian and Precambrian Superior lithologies on the remaining area of the permit. From 1979 to 1984, magnetometry and electromagnetism surveys on the Saraya granite identified uranium mineralisation in conjunction with episyenites, representing geological in situ resources estimated at about 1 500 tU at an average grade of 0.2%.

COGEMA extensively explored uranium in eastern Senegal in the period 1975-1985 (about 400 vertical and oblique drill holes). The drastic drop in the price of uranium, in the context of rather mixed results, led to the discontinuation of the exploration programme. In 1975, the Total Mining Company of Senegal led exploration studies on uranium anomalies associated with phosphates in secondary and tertiary basins of Cape Verde. The results were not encouraging.

In 2007, exploration was revived due to uranium price increases, and as a result Areva (ex COGEMA) purchased the East Saraya licence from the junior South African company UraMin. The Saraya western perimeter was awarded to Kansala Resources on 22 March 2007. The exploration licence was renewed again in 2013 for a period of three years. The results of the work showed that the structural setting of the Saraya granitic complex can be considered favourable for alaskite type uranium mineralisation

Exploration has not identified any uranium resources of economic interest, but have nevertheless contributed greatly to understanding the geology of Senegal, particularly in eastern Senegal, on the upper Precambrian basin, including equivalents that exist throughout West Africa (i.e. the uranium belt of Zaire) prospected in the past by CEA-COGEMA teams. The research carried out in Senegal, as well as in Guinea and Mali, helped establish a detailed map and improved understanding of the geological history of the country.

Recent and ongoing uranium exploration and mining development

There has been no recent exploration and mining development for uranium in Senegal.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

The national potential is estimated at 1 500 tU at an average grade of 0.2% U.

Historically, Senegal has not reported identified resources. However, considering the amount of drilling completed in the Saraya area and the resource estimation completed by COGEMA, the previously reported undiscovered resources should be classified as inferred resources.

Undiscovered conventional resources (prognosticated and speculative resources)

Senegal previously reported undiscovered conventional resources of 1 500 tU, which are now classified as inferred resources after an IAEA Uranium Group Secretariat review of the drilling effort undertaken to identify the resources.

Unconventional resources and other materials

Senegal does not report unconventional resources.

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	0	1 500
Total	0	0	0	1 500

Slovak Republic*

Uranium exploration and mine development

Historical review

Beginning in 1947, uranium exploration (surface radiometric prospecting) was performed in different areas of the Slovak Republic (part of the former Czechoslovakia). Surface and airborne radiometric techniques, along with prospecting, borehole logging, geoelectric and geomagnetic prospecting and hydrogeochemistry, were used to determine six regions of uranium mineralisation. Based on the results of this early work, it was concluded that the Slovak Republic had few uranium resources of economic interest.

Between 1985 and 1990, state exploration activities in the eastern part of the Slovak Ore Mountains led to the estimation of resources of economic interest at the Košice deposit, but the deposit was not mined. Uranium mining was terminated in 1989-1990 and an attenuation programme for exploration and mining was instituted between 1990 and 2003, bringing state-funded exploration activities to an end. No uranium exploration occurred between 1990 and 2005.

Ludovika Energy Ltd (a subsidiary of European Uranium Resources) continued exploration in two prospecting areas in the east of the Slovak Republic. The most promising exploration licence concerns uranium mineralisation in Kuriskova, near Košice, which is located within the Jahodná pri Košiciach recreational area. On 30 January 2012, European Uranium Resources announced the results of a preliminary feasibility study prepared by Tetra Tech, Inc. of Golden, Colorado. Highlights of the preliminary feasibility study included an initial rate of return of 30.8%, a 1.9-year payback, a net present value of USD 277 million at an 8% discount rate (pre-tax, base case assuming prices of USD 68/lb U_3O_8 and USD 15/lb Mo). Indicated resources total 28.5 million pounds of U_3O_8 (10 960 tU) and inferred resources amount to 12.7 million pounds of U_3O_8 (4 885 tU), using a cut-off of 0.05% U. Operating costs covering the life of the mine have been set at USD 22.98/lb U_3O_8 (USD 59.75/kgU), assuming a net molybdenum credit of about USD 1.27 per pound of U_3O_8 (USD 3.30/kgU). The project could have been developed as an underground mine and a processing facility that would utilise conventional alkaline (non-acid) processing.

In April 2014, European Uranium Resources Ltd agreed to sell its Kuriskova and Novoveská Huta uranium projects to Forte Energy NL. In October 2014, European Uranium Resources Ltd announced that the company had executed a definitive agreement that allowed Forte Energy NL to earn a 50% interest in the company's uranium projects. The interest would be held through ownership of 50% of the company's wholly owned Slovak subsidiaries at that time, Ludovika Energy and Ludovika Mining, which held the mineral licences comprising the Kuriskova and Novoveská Huta uranium projects.

In November 2014, European Uranium Resources Ltd reported that the management committee of the joint venture between Forte Energy NL and European Uranium Resources Ltd had met in the Slovak Republic to discuss and develop plans for the Kuriskova project to be funded solely by Forte. These discussions were unsuccessful, and exploration licences expired in 2015. Further discussions led to the Ministry of Environment rejecting Ludovika Energy's application to identify a new exploration area for rare earth elements in the Jahodná-Kurišková area in late 2016.

* Report prepared by the NEA/IAEA based on Red Book 2016, partial Red Book 2022 questionnaire response and available public data.

In 2011, Crown Energy Ltd (a subsidiary of GB Energy) drilled five exploration holes (totalling 204 m). During 2012, GB Energy completed exploration programmes over the Kluknava and Vitaz-II exploration areas. In June 2012, following an extensive review of archival material, Crown Energy Ltd uncovered data from a 1960s drilling programme in the vicinity of the Kluknava and Vitaz-II licence areas. Given the volume of data generated from this historic activity, GB Energy deferred new exploration work until the data could be fully analysed. Detailed results of the 1960s programme were expected to be published in 2014. However, no new information on prospection activities appeared publicly and exploration licences expired in 2014.

The activity and exploration results of Beckov Minerals Ltd in the Horka nad Vahom-Kalnica area were not published.

Recent and ongoing uranium exploration and mine development activities

Since 2015, there have been several protests and lawsuits over the allocation of exploration areas, as well as political discussions about banning uranium mining and exploration in the country, and no new uranium exploration licences have been issued in the Slovak Republic.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

No new identified conventional resources have been assessed since 2012, when a pre-feasibility study was finalised and a reserves calculation report for Košice I (Kuriskova area) was approved by the Commission for Reserves Classification (Ministry of Environment of the Slovak Republic). This revised total increased Košice I resources by over 9 000 tU from the total reported in 2011. As of 2021, total indicated and inferred uranium resources in the two registered uranium deposits represent a total of 19 319 in situ tU.

Deposit	Organisation	Ore resources (t)	U resources (tU)
Košice I	Ludovika Energy Ltd	5 427 000	15 830
Novoveská Huta	Ludovika Energy Ltd	3 876 000	3 489

Undiscovered conventional resources (prognosticated and speculative resources)

Prognosticated resources are estimated to occur in areas surrounding identified deposits and a new estimate of prognosticated resources for the Košice deposit was developed. No recent changes have been observed since.

Deposit	Estimated grade (%)	Ore resources (t)	U resources (tU)
Košice I	0.2% U	1 845 432	3 691
Novoveská Huta	0.06% U	12 040 000	7 224

Uranium production

Historical review

During the first period of uranium exploration (1954-1957), a small amount (1.4 tU) was mined in the Novoveská Huta – Hnilcik region. From 1961 to 1990, a total of 210 tU was mined, mainly from Novoveská Huta as a by-product of copper mining, but also from the Muran, Kravany, Svabovce and Vikartovce deposits.

There is no uranium production in the Slovak Republic and none is expected in the future.

Secondary sources of uranium

There is no production and no use of secondary sources of uranium in the Slovak Republic.

Environmental activities and socio-cultural issues

Environmental activities have covered monitoring in the historical mining area of the Novoveská Huta deposit. Monitoring has included chemical analyses of mine water outflow as well as geochemical and geological engineering evaluations of the condition of tailings and waste rock piles.

Partial monitoring of such factors has been part of a national environmental monitoring network focused on natural or anthropogenic geological hazards (as indicated by the acronym ČMS GF). Selected mining sites have been monitored, including the above-mentioned area.

Waste rock management must be performed according to Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC. In the Slovak Republic, related legislation is NR SR (National Council of the Slovak Republic) Act No. 514/2008 Col. on the management of waste from extractive industries and the Decree of the MŽP SR (Ministry of the Environment of the Slovak Republic) No. 255/2010 Col., which executes the act on the management of waste from extractive industries.

Several studies and environmental evaluations of radioactive materials and the impacts of mining in this locality have been conducted:

- Bezák, J. and A. Donát (1996), "Mine Waste Piles and Settling Pits – Evaluation of Natural Radioactivity of Selected Deposit Sites" (*Haldy a odkaliská – zhodnotenie prirodzenej rádioaktivity vybraných ložísk nerastných surovín*). Ministry of the Environment of the Slovak Republic, Uranpres JSC.
- Daniel, J., E. Mašlár and I. Mašlárová (2001), "Effectiveness of Remediation of Uranium Activities on Slovakian Territory" (*Účinnosť revitalizácie po uránovej činnosti na území Slovenska*), Ministry of the Environment of the Slovak Republic, Uranpres JSC.
- Daniel, J., et al. (2005), "Evaluation on Geological Works for U Ores in Selected Regions of the Western Carpathians in the Territory of Slovakia" (*Zhodnotenie geologických prác na U rudy vo vybraných oblastiach Západných Karpát na území Slovenska*), Final Report, Ministry of the Environment of the Slovak Republic, Uranpres JSC.
- Letkovičová, M. and Božíková, K. (2008), Dlhodobá demograficko - epidemiologická štúdia obyvateľstva Spišskej Novej Vsi, Environment, a.s., Centrum bioštatistiky a environmentalistiky, Nitra (Long-term demographic-epidemiologic population study; in Slovak language only).
- Thorne M. C., et al. (2000), "Remediation of Uranium Liabilities in Slovakia", Final Report, AEA Technology, United Kingdom.

Uranium requirements

The Slovak Republic has two nuclear power plants (Bohunice and Mochovce) with a total of four pressurised water reactors of the VVER-440 type. Two reactors are in operation at each site and all four reactors operate continually at increased power (107% of the nominal power). As of 1 January 2021, the total installed capacity amounted to 1 814 MWe net with uranium requirements of 483 tU per year.

In 2009, construction began of an additional two reactors at the Mochovce site (units 3 and 4). In July 2018, the Slovak Republic's Prime Minister stated that the new target dates for completion of units 3 and 4 were 2019 and 2020. However, in April 2019, it was announced that a further delay of eight months was likely as a result of challenges to the permits needed for commissioning. Unit 3 was 99% complete at that time; unit 4, 85%. In April 2020, it was announced that unit 3 would not be operational until November or December 2020. In May 2020, the Slovak Republic's Nuclear Regulatory Authority (UJDSR) announced that during post-installation checks it had found that material used in some pipe connections "did not meet specifications". As a result, Slovenské Elektrárne is to carry out checks on "several thousand" components from the same supplier. The UJDSR stated that it was not possible to determine the impact of the component checks on the timetable for Mochovce 3 at that time. In February 2021, it was reported that opposition from Austrian environmental organisation Global 2000 could delay fuel loading to the third quarter of 2021. In May 2021, the regulator issued an operating licence for unit 3. In October 2021, SE said it expected final regulatory approval before the end of the year, allowing the first electricity to be generated in unit 3 in early 2022. In August 2022, the final authorisation for Mochovce 3 to begin operating was issued by the regulator. On 31 January 2023, Mochovce 3 was connected to the grid.

Design and development work for the use of nuclear fuel with higher enrichment was completed on units 3 and 4 of the Bohunice Nuclear Power Plant and units 1 and 2 of the Mochovce Nuclear Power Plant, and during 2014 fresh nuclear fuel with average enrichment of 4.87% of ^{235}U was loaded into all four reactors.

Supply and procurement strategy

In June 2014, Slovenské Elektrárne signed a contract with the Russian company TVEL to supply fresh nuclear fuel for units 3 and 4 of the Bohunice Nuclear Power Plant and units 1 and 2 of the Mochovce Nuclear Power Plant. The contract covers the period from 2016 to 2021 and includes the fuel fabrication for all four units and the supply of nuclear material for Bohunice unit 4 and Mochovce unit 2. Simultaneously, Slovenské Elektrárne signed a contract with the French company Areva (currently Orano) to supply enriched uranium product for the fabrication of the nuclear fuel for Bohunice unit 3 and Mochovce unit 1, covered by the above-mentioned contract with TVEL.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Energy Policy of the Slovak Republic (Resolution of the Government of the Slovak Republic No. 29/2006)

One of the priorities set to meet energy policy objectives is to utilise domestic primary energy sources for electricity and heat production in an economically effective way.

Energy Security Strategy of the Slovak Republic (Resolution of the Government of the Slovak Republic No. 732/2008)

The objective of the Energy Security Strategy is to achieve a competitive, secure, reliable and efficient supply of all forms of energy at reasonable costs that protects consumers and the environment and promotes sustainable development, security of supply and technical safety.

The high share of nuclear energy in the energy mix of the Slovak Republic relies on dependable sources of a sufficient number of fuel elements, which in Europe are offered only by Russia and France. It is possible that in the future, these fuel element producers could require from customers a counter-value in the form of uranium as a certain form of payment. If this occurs it will be necessary to create the appropriate legislative conditions for the extraction of uranium by amending the relevant laws and strategic documents, including the Raw Materials Policy, since domestic deposits of uranium ore are located near Košice and Spisska Nova Ves – Novoveská Huta.

Legislative and economic support for the efficient and rational use of domestic uranium resources is needed to considerably reduce the dependency on imported energy sources, whose market prices have risen sharply in past years. Increased uranium prices and higher nuclear fuel costs can privilege those states which will be able to supply their own uranium and require its further processing to produce nuclear fuel.

The possibility of extracting uranium in the Slovak Republic is also to be assessed from the perspective of maximum environmental protection. Mining projects must be harmonised with the development of documentation by concerned municipalities and regional governments in conformity with the applicable legislation.

In order to meet the Energy Security Strategy targets, it is necessary to assess the feasibility of uranium extraction in the Slovak Republic. It is important to rationally and effectively support the use of domestic energy sources with the aim of decreasing dependency on imports.

Assessing the viability of uranium mining in the Slovak Republic was one of the priorities of the country's 2008 Energy Security Strategy. However, in May 2014 the government resolved to ban uranium mining in the country unless it is approved by a referendum of local inhabitants. The Slovak Environment Ministry proposed the amendment to the law, which came into effect in June 2015.

European Uranium signs a memorandum of understanding with the Slovak Ministry of Economy

In December 2012, European Uranium Resources Ltd (EUU) reported that it had signed a memorandum of understanding with the Ministry of Economy of the Slovak Republic. The memorandum defines the parameters by which EUU and the ministry will co-operate in advancing the Košice uranium deposit – on which EUU holds the exploration licence – through ongoing feasibility and environmental studies. A pre-feasibility study (PFS) completed by Tetra Tech, Inc. indicates that the Košice uranium deposit can be developed as an underground mine using the best technologies available with minimal environmental impact and that it could be one of the lowest-cost uranium producers in the world.

After the affected municipalities and civic associations voiced disagreement, all the mentioned activities were stopped.

Uranium stocks

The Slovak Republic does not maintain an inventory of natural or reprocessed uranium.

Slovenské Elektrárne has a small stock of enriched uranium in the form of complete fuel assemblies. The number provided in the table "Total uranium stocks", reflects a small amount of fuel assemblies and fuel for first core loading of Mochovce unit 3.

Uranium exploration and development expenditures and drilling effort – domestic

(EUR million)

	2018	2019	2020	2021 (expected)
Industry* exploration expenditures	NA	NA	NA	NA
Government exploration expenditures	0	0	0	0
Industry* development expenditures	NA	NA	NA	NA
Government development expenditures	0	0	0	0

* Expenditures made by private companies. Government expenditures refer to those corresponding to majority government funding.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	10 950*	10 950*	10 950*	80
Total	0	10 950	10 950	10 950	

* Indicated resources (pre-feasibility study).

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	10 950*	10 950*	10 950*	80
Total	0	10 950	10 950	10 950	

* Indicated resources (pre-feasibility study).

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Volcanic-related	0	10 950*	10 950*	10 950*
Total	0	10 950	10 950	10 950

* Indicated resources (pre-feasibility study).

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	4 881*	8 369*	8 369*	80
Total	0	4 881	8 369	8 369	

* Inferred resources (pre-feasibility study).

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	4 881*	8 369*	8 369*	80
Total	0	4 881	8 369	8 369	

* Inferred resources (pre-feasibility study).

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Volcanic-related	0	4 881*	8 369*	8 369*
Total	0	4 881	8 369	8 369

* Inferred resources (pre-feasibility study).

Conventional prognosticated resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	3 691	10 915

Note: Category shift concerning new reserves calculation and estimated ore quality.

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining*	50**	0	0	50	0
Underground mining*	161**	0	0	161	0
Total	211	0	0	211	0

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

** Estimate.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	211	0	0	211	0
Total	211	0	0	211	0

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Volcanic-related	211	0	0	211	0
Total	211	0	0	211	0

Net nuclear electricity generation (TWh net)

	2019	2020
Nuclear electricity generated (TWh net)	15.369	15.444

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
1 814	1 814	1 814	2 254	2 694	2 694	2 694	2 694	2 694	2 694

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
483	483	490	533	491	534	490	533	491	534

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	0	NA*	NA	0	NA
Producer	0	0	0	0	0
Utility	0	227.63*	0	0	0
Total	0	NA	NA	0	NA

Note: Data provided by Slovenské Elektrárne, a.s. (ENEL Group).

* In form of complete fuel assemblies.

Slovenia

Uranium exploration and mine development

Historical review

Exploration of the Žirovski Vrh area began in 1961. In 1968, the P-10 tunnel was developed to access the orebody. Mining began at Žirovski Vrh in 1982 and uranium concentrate production (as yellow cake) began in 1985. The mine ceased operations in 1991.

Recent and ongoing uranium exploration and mine development activities

Expenditures for exploration ended in 1990. There are no recent or ongoing uranium exploration activities in Slovenia.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

A resource assessment of the Žirovski Vrh deposit was carried out in 1994. Reasonably assured resources are estimated to amount to 2 200 tU (in situ) with an average grade of 0.14% U in the <USD 80/kgU cost category. In situ inferred resources total 5 000 tU in the <USD 80/kgU cost category, and 10 000 tU in the <USD 130/kgU cost category at an average grade of 0.13% U. This deposit occurs in the grey sandstone of the Permian Groeden Formation, where the orebodies occur as linear arrays of elongated lenses within folded sandstone.

Undiscovered conventional resources (prognosticated and speculative resources)

Undiscovered resource estimates remain the same as previously reported.

Uranium production

Historical review

The Žirovski Vrh uranium mine, located 20 km south-west of Škofja Loka, was the only uranium production centre in Slovenia. Ore production began in 1982 and the associated ore processing plant (annual production capability of 102 tU) began operations in 1984, initially treating stockpiled ore. The ore, which occurs in numerous small bodies in the mineralised coarse-grained sandstone, was mined selectively using a conventional underground room and pillar, cut-and-fill operation with a haulage tunnel and ventilation shaft. In 1990, operations were terminated. Cumulative production from the Žirovski Vrh mine and mill complex totalled 386.7 tU (calculated).

Status of production capability

In 1992, a decision made to close and decommission the Žirovski Vrh mine and mill complex and there has been no production at the facility since. All production was carried out in the former Yugoslavia. In 1994, the Slovenian government adopted the plan for decommissioning the facility. The production facility was dismantled and no longer exists.

Environmental activities and socio-cultural issues

The government-owned Žirovski Vrh Mine Company manages all activities connected with the rehabilitation of the former uranium production site, consisting of underground mining facilities, surface milling facilities, the waste rock pile and tailings disposal site. It obtains all remediation permits required, performs the remediation works and monitors the environmental impact of the site during the remediation phase. After finishing the remediation work, the remaining disposal sites and the mine water effluents are put under long-term environmental surveillance, which is carried out by the national Agency for Radioactive Waste Management. The mine effluents are monitored for uranium, radium and other chemical contaminants, and the disposal sites are monitored for radon exhalation and uranium and radium in water effluents.

The annual effective dose contribution from all mine sites has significantly decreased as a result of remediation activities. Since 2011 it has dropped below 0.1 mSv/a, from about 0.4 mSv/a during operation. Background annual effective levels are 5.5 mSv/a in the area surrounding the mine. Associated with the uranium production site are a hydrometallurgical tailings disposal site and a waste rock disposal site. Environmental remediation of the disposal site for hydrometallurgical tailings is in its final stage, the critical factor being the stability of the site. All remediation work is finished on the site of the mine waste pile, and in 2015, the long-term environmental surveillance of the site started.

Monitoring

The mine's air and water effluents have been monitored on a regular basis since the start of the ore production in 1982. The programme was modified when production stopped in 1990 and is ongoing. Emissions to surface waters and air are monitored, and doses to the local population have been calculated since 1980. Treatment of the mine's effluents is not planned, considering the low concentrations of radioactive contaminants.

In 2019, the monitoring network was renovated and upgraded with an additional nine deep piezometers. As part of the long-term surveillance and maintenance programme, the surfaces of the Jazbec mine waste disposal site and the Boršt hydrometallurgical tailings disposal site are controlled regularly. In the event of heavy rain or an earthquake, additional site controls are conducted. The rate of sliding of the base of the Boršt hydrometallurgical tailings disposal site is measured in real time, using a GPS system, at control points on the hydrometallurgical tailings. Since 2018, geodetic surveillance has been carried out twice a year. A network, entitled "Vrtine-2", has been added to the basic landslide surveillance network.

Tailings impoundment

There is one 4.2 ha specially designed long-term site for hydrometallurgical tailings, called Boršt. It is situated on the slope of a hill between 535 and 565 m above sea level. At this disposal site, 610 000 tonnes (t) of hydrometallurgical waste, 111 000 t of mine waste and 9 450 t of material, collected during decontamination of the mill tailings in the Boršt site vicinity, have been disposed, with a total activity of 48.8 TBq. The amount of excavated ore was about 630 000 t and the amount of the processed ore was about 610 000 t.

The tailings have been stored in a dry condition as a result of the filtration of the leached liquor. The surface was topped with a 2-m thick, engineered multilayer soil cover with a clay base to prevent leaching of contaminants, and covered with grass. Although remediation of the site was completed in 2010, it required drainage intervention measures to reduce the groundwater level and slow down landslide movement that was activated beneath the disposal site. The results of additional slope stabilisation work, performed in 2016 and 2017, will help determine if the disposal site meets the conditions for site closure and the beginning of long-term environmental surveillance.

In 2018, the Expert Project Council for monitoring the remediation work on the hydrometallurgical tailings prepared a final report. The effects of the maintenance, monitoring and intervention measures (performed between 2010 and 2018) to reduce the groundwater impact on the stability of the Boršt hydrometallurgical tailings disposal site were assessed, as well as the current state of the Boršt disposal site. In 2019, the monitoring network of the Boršt hydrometallurgical tailings disposal site was renovated and upgraded with nine additional deep piezometers. The safety report for the Boršt hydrometallurgical tailings disposal site is under revision. This is the basic document for the closure of the disposal facility and the transition to long-term surveillance and maintenance, which will be carried out by the Agency for Radioactive Waste Management (ARAO) as part of a mandatory service of general economic interest.

Waste rock management

All waste rock piles were relocated to the central mine waste pile, Jazbec. All other sites have been restored to a green field condition. The 6.7 ha Jazbec facility contains 1 910 425 t of mine waste, low-grade uranium ore, red mud, filter cake from the mine water treatment station, and contaminated material from the decommissioning of mining and milling facilities, with a total activity of 21.7 TBq. It is covered with an engineered two-metre-thick multilayer of soil and planted grass. A concrete drainage tunnel was constructed at the bottom of the waste rock pile to drain seepage and groundwater into a local stream. Environmental remediation works at the Jazbec disposal site were completed and the administrative procedure for site closure finalised in 2015. The responsibility for long-term surveillance and maintenance of the site was transferred to the ARAO in 2015.

Uranium requirements

The sole nuclear power plant in Slovenia is based at Krško and called Nuklearna Elektrarna Krško. It started commercial operation in January 1983 and was modernised in 2000 with replacement steam generators that increased net capacity to 676 MWe. Net capacity was increased in 2006 to 696 MWe with low-pressure turbine replacement and again in 2009 to 698 MWe after modernisation of the turbine control system with the installation of a new high-pressure turbine in 2022. The power plant is 50% owned by Slovenia and Croatia.

There has been no significant change in the Slovenian nuclear energy programme in the last few years. Uranium requirements for Nuklearna Elektrarna Krško are relatively stable and account for about 149 tU per year. The current fuel cycles are 18 months in duration and are planned to continue on this cycle basis. In 2012, the Slovenian Nuclear Safety Administration approved the ageing management programme, a prerequisite for the operation of Nuklearna Elektrarna Krško beyond 2030 until the year 2043. In January 2023 the Slovenian Ministry of Environment issued the final approval for NPP Krško until 2043 following the completion of an environmental assessment.

Supply and procurement strategy

The total uranium requirement of Nuklearna Elektrarna Krško per operating cycle remain unchanged and as reported in previous editions of the Red Book. There are no operating or strategic uranium reserves in Slovenia and supply is imported based on requirement contracts.

The current uranium supply contract covers requirements until 2028. The current procurement strategy utilises enriched UF_6 supplied to the fuel manufacturer from the uranium supplier when it is required for fuel assembly construction. No physical deliveries of U_3O_8 or UF_6 are made to the Nuklearna Elektrarna Krško site. The manufactured fuel assemblies arrive just before they are used for power production. There are no plans in the foreseeable future to build a uranium stockpile by Nuklearna Elektrarna Krško. The strategy for commercial spent nuclear fuel management currently does not include the use of reprocessed uranium and Nuklearna Elektrarna Krško is not licensed for MOX use.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Slovenia is not a uranium-producing country. Uranium stocks are imported for the commercial operation of Nuklearna Elektrarna Krško as final products (manufactured nuclear fuel assemblies).

Uranium stocks

There is no uranium stock policy in Slovenia. Nuklearna Elektrarna Krško has no uranium stocks and there is no intention to create such a policy. All required uranium stocks are purchased on a "just-in-time" basis.

Uranium prices

This information is considered confidential.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining	0	2 200	2 200	2 200
Total	0	2 200	2 200	2 200

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unspecified	0	2 200	2 200	2 200
Total	0	2 200	2 200	2 200

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	2 200	2 200	2 200
Total	0	2 200	2 200	2 200

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining	0	5 000	10 000	10 000
Total	0	5 000	10 000	10 000

Inferred conventional resources by processing method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unspecified	0	5 000	10 000	10 000
Total	0	5 000	10 000	10 000

Inferred conventional resources by deposit type
(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	5 000	10 000	10 000
Total	0	5 000	10 000	10 000

Prognosticated resources
(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	1 060	1 060

Historical uranium production by production method
(tonnes U in concentrate)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021(expected)
Underground mining*	386.7	0	0	386.7	0
Total	386.7	0	0	386.7	0

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Net nuclear electricity generation

	2019	2020
Nuclear electricity generated (TWh net)	5.533	6.041

Installed nuclear generating capacity to 2040
(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
685	690	666	698	666	698	666	698	666	1 773

Note: Low and high values were taken as dependable power and maximum designed net power, respectively.

Annual reactor-related uranium requirements to 2040 (excluding MOX)
(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
149	149	119	179	119	179	119	179	119	179

Note: The Krško nuclear power plant operates 18-month cycles with a fresh fuel load of 224 tonnes of natural uranium equivalent. In some years no uranium supply will be required (e.g. 2021, 2024 and 2027). The values in the table are the average yearly values (i.e. 224 tU x 12/18 = 149 tU). Low and high variability is ±20% from the expected value; this is calculated from maximum change that could occur from a change in fuel assembly design or variation in cycle length (i.e. 12-24 months). The variability shown in some previous reports (2005, 2007, 2009 and 2011) was lower than shown in more recent editions, as it was based on observed 18-month cycle-to-cycle differences and may not be a fair representation in such a long timescale prediction. Since 2013, the larger variability has been reported.

South Africa*

Uranium exploration and mine development

Historical review

South Africa has been an important player in the international market since it first started producing uranium in 1952. It has steadily and consistently produced uranium since then, albeit at a lower level in recent years. Seven of the fifteen deposit types defined in the Red Book are found in South Africa, namely paleo-quartz-pebble conglomerate, sandstone, lignite and coal, intrusive, surficial, phosphate and granite-related deposits. A major part of the resource base is hosted by the quartz-pebble conglomerates and derived tailings, with significant amounts of resources in the sandstone and coal-hosted deposits. The other deposit types make a relatively small contribution to the national uranium resource inventory.

There are six distinct uranium provinces in South Africa. The oldest are the Palaeozoic-aged Mozaan basin in the north-east and the slightly younger Witwatersrand Basin in central South Africa. The Precambrian-aged Palabora and Pilanesberg carbonatite complexes lie in the north, with the Precambrian to Cambrian granite complexes in the north-west. The sandstone deposits of the Karoo in the south-central parts, as well as the coal-hosted deposits of the Springbok Flats are of Permo-Triassic age. The youngest are the Tertiary to recent surficial deposits in the Northwest Cape and the phosphorite deposits off the south-west coast.

The surge in uranium prices between 2005 and 2007 stimulated significant corporate interest in South Africa. Much of the ground over the Witwatersrand Basin was held by existing mining companies and extensive re-evaluations of uranium resource holdings were undertaken. Of great interest were the resources held in the vast tailings dams created by over 100 years of gold mining. Gold Fields, Rand Uranium, Harmony and AngloGold Ashanti launched detailed feasibility studies into the resources contained in tailings.

Available areas with known uranium occurrences, such as in the Karoo Basin and Springbok Flats, were quickly acquired by companies UraMin, Holgoun Energy and others. UraMin was subsequently acquired by Areva, which included the Trekkopjie deposit in Namibia and the Ryst Kuil Channel in the Karoo Basin. Smaller companies obtained prospecting licences over lesser-known deposits in the Karoo Basin, as well as deposits in the granitic and surficial terrains in the northwest of the country.

Peninsula Energy operated in South Africa through its subsidiary Tasman RSA Holdings (Pty) Ltd and had a total of 41 prospecting rights covering 7 774 km^2 in the Karoo Uranium Province. Peninsula Energy identified new areas of uranium mineralisation in the stacked sandstone units which host extended uranium mineralisation beyond the historic drilling limits, thereby increasing the resource potential. In December 2012, Peninsula Energy acquired all of Areva's properties located in the Karoo Uranium Province, including the Ryst Kuil deposit. Since the commencement of exploration in 2006, Tasman has completed approximately 31 000 m of reverse circulation and diamond drilling, and geophysically logged an additional 15 000 m of open historic holes. In February 2013, Tasman commenced drilling along the Ryst Kuil channel in the Eastern Sector of its Karoo projects, which has returned encouraging initial results.

* Report prepared by the NEA/IAEA, based on previous Red Books and public data.

In 2013, Peninsula released positive results from an initial scoping study, enabling the commencement of the pre-feasibility study in the second half of 2013, which included extensive metallurgical test work. In June 2014, the company submitted mining rights applications over all their prospecting areas in the Karoo region. The application process was expected to take up to two years and hence the planned start of mine development was delayed from 2016 to 2018.

In 2012, HolGoun Uranium and Power Limited completed a pre-feasibility study of its project in the Springbok Flats Basin, where uranium is hosted by coal, then followed up with a more detailed economic feasibility study. The economic feasibility study comprised resource and reserve estimations, bulk-sampling and pilot plant test work, geotechnical and groundwater study, mine and underground infrastructure design, overall environmental issues, financial and economic evaluations, and a mining rights application. The initial development of this project envisaged an annual production capacity of about 700 tU_3O_8 (595 tU) at a feed grade of 0.096% U of ore during the first seven years of production. Thereafter, the annual production was planned to be about 500 tU_3O_8 (425 tU) at a feed grade of 0.063% U of ore.

Gold One International Ltd acquired the Rand Uranium properties, as well as the Ezulwini mine, in 2012. One of the key objectives associated with these acquisitions was to re-establish the Cooke underground and Randfontein surface operations as gold mines and subsequently to develop uranium co-product potential. The Cooke underground operations comprise Cooke 1, 2, 3 and Ezulwini. Ezulwini was integrated into the Cooke underground complex as Cooke 4. Ongoing exploration and resource development work highlighted numerous potential resource extensions. A feasibility study was completed in 2012 on a high uranium yielding area at Cooke 3, which consists of both unmined ground and several higher-grade pillars. The area is associated with existing underground development. The feasibility study considered uranium extraction through the Cooke 4 uranium plant (Ezulwini). The Randfontein surface operations host gold and uranium surface resources which present attractive opportunities for future extraction. These tailings include the Cooke tailings dam, the Millsite complex, Lindum, Dump 20 slime, and the Old 4 dam.

In 2012, Harmony Gold Ltd developed two uranium projects to the feasibility stage: Harmony Uranium TPM (Tshepong, Phakisa, and Masimong) and the Free State Tailings Uranium Project. The initial plans were that the TPM project would be extracting uranium from the Tshepong, Phakisa, and Masimong underground mines while the Free State Tailings Uranium Project would be extracting uranium from the old tailings storage facilities owned by Harmony. The feasibility study of the TPM project was supported by a demonstration plant campaign and associated metallurgical test work. However, these projects have been deferred because of financial constraints.

Namakwa Uranium conducted uranium exploration on the Henkries Project. Most of the delineated resources, mainly in Henkries Central, occur within 20 metres from the surface. Given the shallow and soft nature of the deposit, as well as good infrastructure serving the project area, the project was regarded as potentially viable for future uranium extraction. Xtract Resources conducted due diligence with a view to acquiring the Henkries Project in the Namaqualand, Northern Cape Province in 2014. However, Xtract has decided not to go ahead with the acquisition of the Namakwa Uranium deposit as it has found that the project does not meet its investment criteria.

Recent and ongoing uranium exploration and mine development activities

In 2017, Peninsula completed draft environmental impact assessment and environmental management programme reports for the Ryst Kuil and Quaggasfontein areas (Karoo projects). The proposed mining operation was to be known as the Tasman RSA Mines and would be operated as a single entity, but with multiple production centres (Kareeport, Ryst Kuil, and Quaggasfontein) feeding a central processing plant to be located near the main ore body within the Ryst Kuil project area. In April 2018, Peninsula announced its decision to withdraw from the Karoo projects in which it had a 74% interest. It suspended all development activities including preparation of exploration and mining right applications.

AngloGold Ashanti's operations in South Africa are all located in the Witwatersrand Basin, in two mining districts: the Vaal River and West Wits areas. The Vaal River Surface operations are located to the north of the Vaal River, close to the town of Orkney in the North West province. The Mine Waste Solution (MWS) operations are located approximately 15 km from the town of Klerksdorp near Stilfontein within 20 km of the Vaal River Surface operations. The MWS feed sources are scattered over an area that extends approximately 13.5 km north-south and 14 km east-west. The West Wits surface operations are located near the town of Carletonville, straddling the border between the North West and Gauteng provinces. These operations extract gold and uranium from the low-grade stockpile material emanating as a by-product of the reef mining activities within the mines in the Vaal River area. In October 2017, AngloGold Ashanti announced that it was selling assets, including the Moab Khotsong mine and related infrastructure, its interest in Nuclear Fuels Corp of South Africa, and its interest in the Margaret Water Company to Harmony Gold Mining. Anglo Gold Ashanti kept the Mponeng mine and MWS surface operations. As of 1 January 2019, AngloGold Ashanti uranium resources of Vaal River and MWS operations amounted to 39 466 tU of reasonably assured resources (6 131 tU of measured resources and 33 335 tU of indicated resources).

In 2014, Sibanye Gold Ltd acquired the Cooke assets and Randfontein operations from Gold One Ltd, and also the Witwatersrand Consolidated Gold Resources Limited (Wits Gold) assets. A detailed feasibility study of the West Rand Tailings Retreatment Project (WRTRP) was completed by mid-2015. The definitive feasibility study focused on leveraging existing surface infrastructure as well as the available uranium treatment capacity at the Ezulwini gold and uranium processing plant to sustain surface gold and uranium production prior to the development of the central processing plant.

The Driefontein, Kloof, and Cooke surface operations and associated processing facilities are located on the West Rand of the Witwatersrand Basin, while Beatrix is in the southern Free State goldfields. Sibanye-Stillwater also has an interest in surface tailings retreatment facilities located from the East Rand to the West Rand through a 38.05% stake in DRDGOLD Limited (DRDGOLD).

As of 1 January 2019, Sibanye-Stillwater resources amounted to 10 338 tU of reasonably assured resources (3 288 tU of measured resources and 7 050 tU of indicated resources), 35 tU of inferred resources at the Beatrix underground mine, and 19 894 tU of reasonably assured resources (16 072 tU of measured resources and 3 822 tU of indicated resources) at WRTRP. In 2018, uranium resources declined due to the sale of a portion of WRTRP to DRDGOLD. The surface rock dumps at Driefontein were depleted in 2018.

In August 2018, Mintails Mining South Africa (Pty) Ltd and several related companies announced their liquidation. Mintails used to mine and process gold and uranium from waste piles and open pits in Krugersdorp near Johannesburg.

Uranium resources

The last official country report by South Africa was in 2016. New resource estimates have been made since 2016, but mainly for tailings and a few deposits.

In 2020, resource re-estimations were completed for the following deposits: Beatrix (quartz-pebble conglomerate), Cooke surface dumps (tailings), Freestate-Harmony (tailings), Kopanang (tailings), Mispah (tailings), Moab Knotsong (quartz-pebble conglomerate), Stilfontein (tailings) and Vaal River (tailings).

The following table shows the changes of recoverable resources (tU) between 2019 and the date of re-estimation for these deposits. As for the previous estimates, the new resource estimates give a breakdown according to confidence level (RAR and IR), but not per cost category.

Resource estimates, as of 1 January 2021, have been obtained by discounting the resource changes to the <USD260/kgU cost category.

Deposit	Type	RAR 2018 (tU)	RAR 2021 (tU)	Change (tU)	IR 2018 (tU)	IR 2021 (tU)	Change (tU)
Beatrix	QPC	7 444	7 450	6	25	27	2
Cooke	Tailings	14 325	14 318	(7)	0	0	0
Freestate	Tailings	11 277	8 862	(2 415)	0	0	0
Kopanang	Tailings	2 394	881	(1 513)	296	0	(296)
Mispah	Tailings	6 329	5 539	(790)	0	0	0
Moab Knotsong	QPC	7 811	7 001	(810)	2 609	2 223	(386)
Stilfontein	Tailings	12 832	11 632	(1 200)	0	0	0
Vaal River	Tailings	15 525	19 940	4 415	0	0	0
Total		77 937	75 623	(2 314)	2 930	2 250	(680)

Identified conventional resources (reasonably assured and inferred resources)

The total recoverable identified conventional resources for South Africa, as of 1 January 2021, amounted to 444 749 tU (RAR: 255 713 tU, IR: 189 036 tU).

The Witwatersrand Basin contains about 79% of total identified uranium resources in South Africa, in both the underground, hosted by quartz-pebble conglomerates, and their resulting tailings storage facilities. Approximately 47% of the total national identified resources are in the Witwatersrand underground operations, 28% in their associated tailings facilities, 20% in the Springbok Flats Basin, and about 5% in the sandstone-hosted deposits of the Karoo Basin. The uranium pay limit in most parts of the Witwatersrand Basin is calculated on a by-product basis, according to which the uranium is not classified as a resource unless it occurs in an area of gold mineralisation that satisfies the estimated gold cut-off grades. In addition, uranium production in these projects only includes the costs of transporting ore from the underground or tailings operations to the processing plants and the treatment of uranium, while gold carries all other costs.

Undiscovered conventional resources (prognosticated and speculative resources)

Undiscovered conventional resources amount to 850 000 tU, which includes the <USD 260/kgU and unassigned cost categories.

The Witwatersrand Basin has a total of about 470 tailings storage facilities with uranium resources, most of which are not included as reasonably assured and inferred conventional resource totals. The Karoo Uranium Province is estimated to contain between 90 000 and about 150 000 tU. This estimate has not changed since the last reporting period.

Unconventional resources and other materials

As reported in the 2011 edition of the Red Book, a field of manganiferous phosphate nodules was identified off the west and southwest coast of South Africa on the continental shelf. The nodules contain low grades of uranium and are currently considered uneconomic with respect to both phosphate and uranium extraction. Renewed interest in phosphate-hosted uranium deposits, however, may generate future investigation. The unconventional resources have been previously estimated to amount to 180 000 tU and are unchanged for this reporting period.

Uranium production

Historical review

South Africa has been a consistent producer of uranium since 1952, but its international importance has declined in recent years. In the late 1970s and early 1980s, it ranked as the second or third-largest producer in the world, but since the end of the 1990s output has declined significantly, and by 2018, South Africa ranked 12th in global uranium production. Peak production was achieved at over 6 000 tU/yr in the early 1980s, when it accounted for 14% of total world output.

Most of South Africa's historical uranium production was derived from quartz-pebble conglomerate deposits with a small proportion being from the Palabora copper-bearing carbonatite. Current production is sourced from the quartz-pebble conglomerate deposits and associated tailings.

The majority of past production was as a by-product of gold or, to a minor extent, copper. Only two primary uranium producers have existed in South Africa. The first was the Beisa mine in the Free State in the early 1980s, and the second was the Dominion Reefs Uranium Mine near Klerksdorp, which operated in the early 2000s.

In 2019 and 2020, uranium production amounted to 185 tU and 62 tU respectively at the Harmony Gold Vaal River operation (Moab Knotsong mine). In 2021, expected production in South Africa is estimated at 192 tU.

At the end of March 2020, the government imposed a 21-day lockdown in response to the coronavirus pandemic. As part of the lockdown, all mining operations (apart from coal mines supplying Eskom) were initially suspended. The lockdown regulations were amended in mid-April 2020 to allow mining to resume at up to 50% of normal capacity.

Status of production facilities, production capability, recent and ongoing activities and other issues

AngloGold Ashanti acquired the MWS tailings retreatment operation in the Vaal River region in July 2012. MWS comprises tailings storage facilities that originated from the processing of ore from the Buffelsfontein, Hartebeestfontein and the Stilfontein gold mines. After selling its Vaal River assets to Harmony Gold Mining in early 2018, operations at the NWS uranium plant ceased in 2018.

Uranium production from the Sibanye-owned Cooke operations began in May 2014. The Cooke shafts were used to mine multiple reefs. Uranium processing was done at the Cooke 4 (Ezulwini) Uranium plant. Uranium production at the Ezulwini-Cooke plant and mine operations ended in 2016, and the associated surface rock dumps at Driefontein were depleted in 2018.

The Moab Khotsong mine is located in the northern part of South Africa, in North West province, about 180 kilometres southwest of Johannesburg. Moab Khotsong represents one of the largest gold and uranium reserves in South Africa having estimated reserves of 57.2 million tonnes of ore grading 0.053% uranium and 8.2 g/t of gold. Moab Khotsong claims to be home to the world's deepest mine shaft at 3 000 metres. Harmony Gold acquired Moab Khotsong from AngloGold Ashanti Limited on 1 March 2018 for USD 300 million. The assets were the Moab Khotsong mine and related infrastructure, its entire interest in Nuclear Fuels Corp of South Africa and its entire interest in the Margaret Water Company.

Ownership structure of the uranium industry

In April 2018, Peninsula announced its decision to withdraw from the Karoo projects, in which it had a 74% interest. It suspended all development activities including preparation of exploration and mining right applications.

In 2014, Sibanye assumed control of the Cooke underground and surface operations, including the Randfontein operations, from Gold One International Limited (Gold One), and concluded the acquisition of Witwatersrand Consolidated Gold Resources Limited. In 2018, Sibanye sold a portion of WRTRP to DRDGOLD.

Future production centres

Future production centres could include the Dominion Reef mine and Beaufort West deposit (Karoo Basin).

Environmental activities and socio-cultural issues

Exploration and mining companies are committed to the responsible use and management of the natural resources under their prospecting and mining rights. Site visits and inspections are conducted regularly to verify that the commitments detailed in their environment management programmes are being adhered to. Exploration and drilling include a responsibility to rehabilitate each site once drilling has been completed. In terms of applications for mining rights, and as part of the Social and Labour Plan, companies are required to inform the interested and affected parties in the proposed mining area of its intended activities.

The Broad-Based Socio-Economic Empowerment Charter for the South African Mining and Minerals Industry (The Mining Charter), which gives effect to the Mineral and Petroleum Resources Development Act No. 28 of 2002, is aimed at transforming the mining industry to redress historical imbalances by substantially and meaningfully expanding opportunities for historically disadvantaged South Africans (HDSA). The charter has given mining companies provision to offset the value of the level of beneficiation achieved against a portion of its HDSA ownership requirements of up to 11% as compared to the current required level of 26% (to be achieved by the end of 2014). Furthermore, mining companies are required to procure a minimum of 40% of their capital goods, 70% of services and 50% consumables from Black Economic Empowerment entities.

AngloGold Ashanti has designed a framework, following extensive stakeholder engagement, to integrate community development into core business activities, while providing support for national development policies and objectives, particularly those addressing youth unemployment. AngloGold Ashanti's contribution to education in both local and labour-sending communities is a priority. In addition, the Merafong Agricultural Project, which employs 20 people, is funded by AngloGold Ashanti. Other social responsibilities included economic initiatives in the labour-sending areas such as the remote villages of the Eastern Cape Province.

Regulatory regime

The Department of Mineral Resources, the Department of Water Affairs, the Department of Environmental Affairs and the Department of Energy, including the National Nuclear Regulator, perform regulatory functions relating to exploration and mining of uranium in South Africa.

According to the Mineral Resources and Development Act No. 28 of 2002, an applicant of prospecting or mining right must make the prescribed financial provision for the rehabilitation or management of negative environmental impacts before the approval of such rights. If the holder of the prospecting or mining right fails to rehabilitate, or is unable to undertake such rehabilitation, then part or all of the financial provision will be used for rehabilitation. The holder of a prospecting or mining right must annually assess their environmental liabilities and accordingly increase their financial provision to the satisfaction of the Minister of Mineral Resources. If the minister is not satisfied with the assessment and the financial provision, the minister may appoint an independent assessor to conduct the assessment and determine the financial provision. The requirement to maintain and retain the financial provision remains in force until a closure certificate has been issued after the closure of mining or prospecting operation. The minister may still retain a portion of the financial provision as may be required to rehabilitate the closed mining or prospecting operation in respect of latent or residual environmental impacts. No closure certificate will be issued until the rehabilitation has been done and the chief inspector, as well as all the governmental regulatory departments related to uranium exploration and mining, have confirmed that the provisions pertaining to health, safety, environment and management of potential pollution to water have been addressed.

Uranium requirements

Koeberg is South Africa's only nuclear power plant. It has two light-water thermal reactors: Koeberg I, commissioned in 1984, and Koeberg II, commissioned in 1985, with a combined installed capacity of 1 840 MW. Together, they require about 294 tU/yr.

In August 2018, the government announced that it had abandoned plans to build up to 9.6 GWe of new nuclear capacity by 2030. The Integrated Resources Plan (IRP) 2018, an update of that issued in 2010, did not include any new nuclear capacity by 2030. IRP 2010 had outlined a required 52 GWe of new capacity by 2030, with nuclear to provide at least 9.6 GWe of that. An update to the IRP issued in November 2016 called for 1.4 GWe of new nuclear capacity by 2037, and a total of 20 GWe long term. IRP 2016 was released in the context of the Integrated Energy Plan (IEP), which projected a more than threefold increase in electricity demand by 2050.

In May 2020, the Department of Mineral Resources and Energy of South Africa stated that it was to begin working on a roadmap for the construction of 2.5 GWe of new nuclear capacity. It is to consider all options, including small modular reactors.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The National Nuclear Regulator Act No. 47 of 1999, the Nuclear Energy Act No. 46 of 1999, National Radioactive Waste Disposal Institute Act No. 53 of 2008, and the Mineral and Petroleum Resources Development Act No. 28 of 2002, are the basis of national policies relating to prospecting for and mining of uranium in South Africa, as well as the export of uranium and disposal of spent nuclear fuel. More information on these policies can be found at the following links:

- www.gov.za/documents/national-nuclear-regulator-act;
- www.gov.za/documents/nuclear-energy-act;
- www.energy.gov.za/files/policies/act_nuclear_53_2008_NatRadioActWaste.pdf;
- www.gov.za/documents/mineral-and-petroleum-resources-development-act.

Uranium stocks

The information and figures on uranium stocks are classified as confidential, and hence could not be accessed from Eskom (a South African electricity public utility, established in 1923, as the Electricity Supply Commission by the South African Government in terms of the Electricity Act).

Uranium prices

No uranium prices were available.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)*	0	0	7 261	9 672	80.0
Co-product and by-product	0	166 337	228 784	246 041	72.5
Total	0	166 337	236 045	255 713	72.8

* The resources for sandstone-hosted deposits in the Karoo Basin are included in the open-pit method; however, in reality the potential production will be conducted by both open-pit and underground mining. The ratio of resources to each method is unknown at present.

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG*	0	166 337	228 784	246 041	72.5
Conventional from OP	0	0	7 261	9 672	80.0
Total	0	166 337	236 045	255 713	72.8

* Conventional from UG also includes tailings resources from the Witwatersrand Basin.

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	7 261	8 526
Paleo-quartz-pebble conglomerate*	0	166 337	228 784	246 041
Surficial	0	0	0	1 146
Total	0	166 337	236 045	255 713

* Paleo-quartz-pebble conglomerate resources include tailings resources as well.

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)*	0	0	0	70 775	68.0
Open-pit mining (OP)**	0	0	10 467	14 080	80.0
Co-product and by-product	0	61 656	74 361	104 181	75.0
Total	0	61 656	84 828	189 036	72.5

* Underground mining resources only include resources from the Springbok Flats Basin. The resources from underground operations in the Witwatersrand Basin are included in the "co-product and by-product" category.

** Resources in the Karoo Basin are included in the open-pit mining method, even though both open-pit and underground mining method are expected to be used. The recovery factor used for the open-pit method (80%) is speculative only.

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	61 656	74 361	174 956	72.0
Conventional from OP	0	0	10 467	14 080	80.0
Total	0	61 656	84 828	189 036	72.5

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	10 467	13 491
Paleo-quartz-pebble conglomerate*	0	61 656	74 361	104 181
Surficial	0	0	0	589
Lignite and Coal	0	0	0	70 775
Total	0	61 656	84 828	189 036

* Includes tailings resources in the Witwatersrand Basin.

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	74 000	159 000

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
243 000	411 000	280 000

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Co-product/by-product	161 047	185	62	161 294	192
Total	161 047	185	62	161 294	192

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	161 047	185	62	161 294	192
Total	161 047	185	62	161 294	192

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Paleo-quartz-pebble conglomerate	161 047	185	62	161 294	NA
Total	161 047	185	62	161 294	NA

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
0	0	62	100	0	0	0	0	62	100

Mid-term production projection

(tonnes U/year)

2021	2022	2025	2030	2035	2040
192	200	200	NA	NA	NA

Short-term production capability

(tonnes U/year)

2025				2030			
A-I	A-I	B-I	A-II	B-II	B-I	A-II	B-II
0	0	0	1 160	3 000	0	1 160	3 000

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	1 180	2 800	0	0	1 090	2 500

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	15.1	10.6

Installed nuclear generating capacity to 2040

(MWe net)

2025		2030		2035		2040	
Low	High	Low	High	Low	High	Low	High
1 840	1 840	1 840	1 840	1 840	NA	1 840	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2025		2030		2035		2040	
Low	High	Low	High	Low	High	Low	High
294	294	294	294	294	NA	294	NA

Spain

Uranium exploration and mine development

Historical review

Uranium exploration in Spain started in 1951 and was carried out by the Junta de Energía Nuclear (JEN). The initial targets were the Hercynian granites of western Spain. In 1957 and 1958, the first occurrences in Precambrian-Cambrian schists were discovered, including the Fe deposit in the province of Salamanca. In 1965, exploration of sedimentary rocks began and the Mazarete deposit in Guadalajara province was discovered. In 1972, the Empresa Nacional del Uranio S.A., today Enusa Industrias Avanzadas S.A., S.M.E. (hereinafter ENUSA), a state-owned company, was established to take charge of all the nuclear fuel cycle front-end activities. Its shareholders are the Sociedad Estatal de Participaciones Industriales (SEPI), holding 60% of the capital, and the Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT, previously JEN), with the remaining 40%. Exploration activities by ENUSA ended in 1992. Joint venture exploration between ENUSA and other companies continued until the end of 1994. During this period, most of the Spanish territory was surveyed using a variety of methods, adapted to different stages of exploration, and ample airborne and ground radiometric coverage of the most interesting areas was achieved.

Recent and ongoing uranium exploration and mine development activities

Berkeley Minera España S.L.U. (hereinafter Berkeley) was granted one mining licence in the province of Salamanca (covering 2 520 ha) and a total of 26 investigation licences (covering a total of 94 555 ha), as well as one exploration licence covering 19 570 ha spanning the provinces of Salamanca, Cáceres and Badajoz. This company has been actively exploring for uranium for several years, with a focus on several historically known uranium projects located within their tenements.

Berkeley's Salamanca Project comprises the Retortillo, Zona 7 and Alameda deposits (in Salamanca province) and also the Gambuta deposit in Cáceres province, which now, according to Berkeley, accounts for 12.3 Mlb U_3O_8 (4 730 tU) in the measured and 47.5 Mlb U_3O_8 (18 270 tU) in the indicated resource categories, with an additional 29.5 Mlb U_3O_8 (11 350 tU) in the inferred resource category. All deposits are the granite-related type (perigranitic subtype), hosted by a sequence of metasediments which are adjacent to a granite intrusion.

According to the company, Retortillo, Alameda and Zona 7 would achieve a production capacity of 4.4 Mlb U_3O_8/yr (1 690 tU/yr) over a mine life of 14 years.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Total reported in situ identified resources are 89.3 Mlb U_3O_8 (34 350 tU), which include 59.8 Mlb U_3O_8 (23 000 tU) in the reasonably assured category (12.3 Mlb U_3O_8 or 4 730 tU as measured resources and 47.5 Mlb U_3O_8 or 18 270 tU as indicated resources) and 29.5 Mlb U_3O_8 (11 350 tU) as inferred. All resources are reported as in situ and mineable by conventional open pit. According to the feasibility study 95% of resources may be recovered by open-pit mining and 87% factor is applied for processing recovery. The overall recovery factor is about 83%.

Uranium production

Historical review

Production started in 1959 at the Andújar plant (Jaén province) and continued until 1981. The Don Benito plant (Badajoz province) remained in operation from 1983 to 1990. Production at the Fe mine (Salamanca province) started in 1975 with heap leaching (Elefante plant). A new dynamic leaching plant (Quercus) started operation in 1993 and was shut down in December 2000. The licence for the definitive shutdown of production, submitted to regulatory authorities in December 2002, was approved in July 2003.

Status of production capability

Mining activities were terminated in December 2000 with the closure of Saelices el Chico uranium mines and production of uranium concentrates ended in November 2002 when the associated Quercus processing plant was shut down.

A decommissioning plan was presented to the regulatory authorities in 2005. However, it was put on standby a first time due to the need to decommission the former Elefante processing plant and restore mines at the same site before decommissioning Quercus, and then a second time in 2009 due to an agreement between ENUSA and Berkeley to complete a feasibility study on the state reserves in Salamanca province. Despite these delays, once the Elefante processing plant was decommissioned, the mines were restored and the agreement between ENUSA and Berkeley was finalised, a new plan for decommissioning was presented to the regulatory authorities in September 2015. This plan has been subject to several additional information requirements since 2016 and is still being evaluated by the national regulatory body.

In 2019 and 2020, the relevant authorities continued evaluating permits and approvals required to authorise the construction of the Berkeley´s mine.

Ownership structure of the uranium industry

Quercus, the only production facility in Spain still pending decommissioning, belongs to the company ENUSA.

Employment in the uranium industry

There is no uranium production in Spain. Since there are no existing production centres, employment is associated with decommissioning and mine development activities only.

Employment at the former Fe mine totalled 25 at the end of 2020. All of these workers are dedicated to the mining restoration, monitoring and decommissioning programmes.

Berkeley has between 15 and 20 employees, depending on the activity being carried out. Berkeley's activity is focused on the project development of the Salamanca Project, pending several authorisations.

Future production centres

Berkeley announced its intention to bring four potential open-pit uranium mines into production: Retortillo-Santidad, Alameda, Zona 7 and Gambuta (the former three in the Salamanca region and the latter in the Cáceres region). Berkeley applied to the competent authority (autonomous regional government) for an exploitation permit for the Retortillo-Santidad mining project in October 2011, and the mining licence was granted in April 2014 once the Environmental Licence was in place and after a favourable report from the Nuclear Safety Council. In March 2012, according to the nuclear regulations, Berkeley requested site authorisation for the radioactive facility to the Ministry in charge of energy issues (currently the Ministry for the Ecologic Transition and the Demographic Challenge, MITERD), which was granted by September 2015 after a favourable report of the Nuclear Safety Council. This allowed Berkeley to request construction authorisation.

In July 2021, the Spanish Nuclear Safety Council (CSN) issued a negative report on the construction licence for the processing plant. The report is mandatory, and when negative or regarding the conditions imposed, it is binding for action to be taken by the Ministry for the Ecological Transition and the Demographic Challenge (MITECO), who are in charge of granting construction licences. Consequently, MITECO rejected Berkeley Energia's authorisation to build a uranium processing plant at the company's Salamanca project in western Spain.

Secondary sources of uranium

Spain reports mixed oxide fuel, re-enriched tails and reprocessed uranium production and use as zero.

Environmental activities and socio-cultural issues

The conditions of the former uranium production facilities in Spain are as follows:

- Fábrica de Uranio de Andújar (Jaén province): Mill and tailings piles have been closed and remediated, with an ongoing ten-year surveillance and control programme (groundwater quality, erosion control, infiltration and radon control). This programme has been extended.
- Mine and plant "LOBO-G" (Badajoz province): The open-pit and mill tailings dump have been closed and remediated, with a surveillance and control programme (groundwater quality, erosion control, infiltration and radon control) in place until 2004. A long-term stewardship and monitoring programme was begun after the declaration of closure.
- Old mines (Andalucía and Extremadura regions): Underground and open-pit mines were restored, with work completed in 2000.
- Two old mines in Salamanca (Valdemascaño and Casillas de Flores) were restored in 2007, following which a surveillance programme was initiated, ending in 2011. Results were evaluated by regulatory authorities and it was determined that an extension of the surveillance period was required.
- Elefante plant (Salamanca province): The decommissioning plan, including industrial facilities and heap leaching piles, was approved by regulatory authorities in January 2001. The plant was dismantled, and ore stockpiles were levelled and covered in 2004. A monitoring and control programme has been in place since 2005.
- In 2004, the mining restoration plan of the open-pit exploitation in Saelices el Chico (Salamanca province) was approved by regulatory authorities. Implementation of this plan was finished in 2008 and the proposed surveillance and control programme was sent to regulatory authorities for approval. A monitoring and control programme has been in place since then.
- Quercus plant (Salamanca province): Mining activities ended in December 2000 and uranium processing in November 2002. A decommissioning plan was submitted to regulatory authorities in 2005. However, because of the need for the decommissioning of the former Elefante processing plant and for the restoration of some of the mines at the same site before turning to the decommissioning of Quercus, as well as the 2009 agreement between ENUSA and Berkeley, this decommissioning plan was put on standby. In September 2015 a new plan for decommissioning was presented to the regulatory authorities, which after several additional information requirements (corrections submitted in 2017 and 2020), is still pending approval. During this time, a surveillance and maintenance programme has remained active for the plant and associated facilities.

Uranium mining regulatory regime

In Spain, the mining regime is regulated by the Mines Act (Act 22/1973), modified by Act 54/1980, and by Royal Decree 2857/1978. The investigation and use of radioactive ores is governed by this act in those areas that are not specifically considered in the Nuclear Energy Act (Act 25/1964), Chapter IV of which deals with the prospecting, investigation and use of radioactive ores, as well as the commercialisation of such ores and their concentrates.

According to Article 2 of the Mines Act, all-natural deposits and other geological resources in Spain are assets belonging to the public domain, investigation and use of which may be undertaken directly by the state or assigned in accordance with the rules. Pursuant to Article 1 of Act 54/1980, which amends the Mines Act, radioactive ores are part of Section D, i.e. resources of national energy interest.

Pursuant to Article 19 of the Nuclear Energy Act, the prospecting, investigation and use of radioactive ores and the obtaining of concentrates are declared to be open throughout the entire national territory, except in those areas set aside by the state. Individuals or companies who wish to prospect for radioactive ores are required to request an investigation permit from the state and subsequently, if the existence of one or more resources open to rational exploitation is revealed, to request an exploitation licence. This licence confers the right to exploit the resources and is granted for a 30-year period, extendable by similar periods of time to a maximum of 90 years. The permits and licences are granted by the autonomous communities, in keeping with the transfer to them of state competences in mining and energy issues, except when the mining activity in question affects several autonomous communities or state reserves, in which case the competent authority is the Ministry for the Ecological Transition and the Demographic Challenge (MITERD), by virtue of the Mines Act.

The Nuclear Safety Council is the organisation responsible for nuclear safety and radiological protection. In accordance with Article 2 of the act creating the Nuclear Safety Council (Act 15/1980), one of the main competences of the Council is to issue reports to the MITERD on nuclear safety and radiological protection, prior to the resolutions adopted by the latter regarding the granting of authorisations for the operation, restoration or closure of uranium mines and production facilities. These reports are mandatory in all cases and binding when negative in their findings or denying authorisation, or as regards to the conditions established when they are positive.

Regarding restoration plans and financial guarantees for the mining activities, according to the Royal Decree 975/2009 of 12 June on the management of waste resulting from extractive industries and the protection and restoration of the environment affected by mining activities, a restoration plan must be submitted for approval to the mining authority (the autonomous regional government or MITERD, in the case of those mining activities affecting several autonomous communities or state reserves), the approval of which will be given together with the granting of the exploitation licence. The mining authority will neither grant the licence nor approve the plan unless environmental restoration of the site is guaranteed. To that end, two financial guaranties must be set up by the company before starting any mining activity. One must be set up for the rehabilitation of the environment affected by the exploitation of the ores and the second for the management of the generated waste. Both must comply with the objectives and conditions established in the authorised restoration plan even in the case that the company does not exist at the time of the restoration.

Decommissioning of the associated milling facilities is pursuant to the Regulation on Nuclear and Radioactive Installations (RINR, approved by Royal Decree 1836/1999 and modified several times afterwards). As radioactive facilities of the nuclear fuel cycle, these facilities are subject to all previous site, construction and exploitation licences. An exploitation licence requires the applicant to submit decommissioning and closure forecasts, including, among other things, the final management of the radioactive wastes as well as the economic and financial calculations to guarantee closure of the site. The RINR requires the constitution of a financial guarantee before granting an exploitation licence.

The Climate Change Law 7/2021 of 20 May on climate change and the energy transition aims to ensure the nation's compliance with the objectives of the Paris Agreement. It includes a section regarding uranium mining and milling facilities in Spain. No new permits to exploit radioactive mineral deposits will be admitted after the entry into force of the Law, which came into effect in May 2021.

Uranium requirements

As of 31 December 2020, the net capacity of the seven Spanish nuclear reactors under commercial operation (Almaraz units 1 and 2, Ascó units 1 and 2, Cofrentes, Vandellós 2 and Trillo nuclear power plants) was about 7.1 GWe. No new reactors are expected to be built in the near future.

In 2020 the Spanish government approved licence renewals for Almaraz unit 1 until 2027, Almaraz unit 2 until 2028 and Vandellós unit 2 until 2030.

During the first quarter of 2021, the lone Cofrentes unit's licence was renewed until 2030 and a similar decision is expected from the corresponding authorities concerning the requested renewal of both Ascó units I and II for another nine and ten years, respectively. In 2014, the Trillo nuclear power plant received its renewal for operation until 2024.

These renewals of the nuclear power plant licences and their terms were requested and authorised in line with the Comprehensive National Energy and Climate Plan 2021-2030. This plan forecasts the evolution of nuclear energy's contribution to the energy mix according to the subsequent Protocol signed in March 2019 by the electric companies and ENRESA agreeing to a scheduled closure of the nuclear power plants during the period 2027-2035.

Accordingly, for the coming years, uranium requirements for the Spanish nuclear fleet will range from 900 to 1 550 tU/yr, decreasing once the closure dates approach.

Supply and procurement strategy

All uranium procurement activities are carried out by ENUSA on behalf of the Spanish utilities that own the seven nuclear reactors under commercial operation in Spain.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Spain's uranium import policy provides for diversification of supply. The Spanish legislation leaves uranium exploration and production open to national and foreign companies.

Uranium stocks

Spanish regulation provides that a strategic uranium inventory contained in enriched uranium should be held jointly by the utilities that own nuclear power plants. The current stock contains the equivalent of at least 608 tU. Additional inventories could be maintained depending on uranium market conditions.

Uranium exploration and development expenditures and drilling effort – domestic

(EUR)

	2018	2019	2020	2021 (expected)
Industry* exploration expenditures	784 530	785 918	253 749	341 700
Total expenditures	784 530	785 918	253 749	341 700
Industry* exploration drilling (m)	0	0	0	3 350
Industry* exploration holes drilled	0	0	0	13
Total drilling (m)	0	0	0	3 350
Total number of holes drilled	0	0	0	13

* Non-government.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	9 800	23 000	23 000	23 000	83
Total	9 800	23 000	23 000	23 000	83

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	9 800	23 000	23 000	23 000	83
Total	9 800	23 000	23 000	23 000	83

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	9 800	23 000	23 000	23 000
Total	9 800	23 000	23 000	23 000

Inferred resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	11 350	11 350	11 350	83
Total	0	11 350	11 350	11 350	83

Inferred resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	11 350	11 350	11 350	83
Total	0	11 350	11 350	11 350	83

Inferred resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	11 350	11 350	11 350
Total	0	11 350	11 350	11 350

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021(expected)
Open-pit mining*	5 028	0	0	5 028	0
Total	5 028	0	0	5 028	0

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	4 961	0	0	4 961	0
Other methods*	67	0	0	67	0
Total	5 028	0	0	5 028	0

* Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Granite-related	5 028	0	0	5 028	0
Total	5 028	0	0	5 028	0

Uranium industry employment at existing production centres*

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres	79	79	42	42
Employment directly related to uranium production	0	0	0	0

* Since there are no existing production centres in Spain, employment is related to decommissioning and mine development activities only. In 2020 for example, 25 employees were involved in Fe decommissioning and the remainder in Salamanca mine development work. See text for details.

Net nuclear electricity generation

	2019	2020
Nuclear electricity generated (TWh net)	55.8	55.8

Installed nuclear generating capacity to 2040

(MWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
7 069	7 069	7 069	7 069	3 020	5 059	NA	NA	NA	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
1 562	946	1 400	1 550	350	500	NA	NA	NA	NA

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	0	0	0	0	0
Producer	0	0	0	0	0
Utility	NA	608	0	NA	NA
Total	NA	608	0	NA	NA

Tanzania*

Uranium exploration and mine development

Historical review

Uranium was first discovered in Chiwiligo pegmatite in the Uluguru Mountains of Tanzania in 1953. The first general evaluation of the uranium potential of Tanzania was a country-wide airborne geophysical survey for the government between 1976 and 1979. Results revealed many radiometric anomalies in a variety of geological settings.

A uranium exploration programme was subsequently carried out by Uranerzbergbau GmbH between 1978 and 1983 but ended because of declining uranium prices. The targets of this survey were anomalies in the Karoo, in younger surficial sediments, in phosphatic sediments of the Pleistocene age and carbonatite of the Gallapo. Numerous occurrences of surface uranium mineralisation were identified and there is potential for several uranium deposit types in the country.

Interest in uranium exploration was revived after the rise of uranium prices in 2007 and the Tanzanian government issued over 70 licences. Major exploration activities were focused on the identification of sandstone-type uranium deposits in the Karoo Basin in the southern part of the country and surficial-type deposits in the central part of the country.

Since 2007, three companies discovered four uranium deposits and identified JORC and NI-43/101 compliant uranium resources (measured, indicated and inferred), as presented in the table below. Total in situ resources amounted to 72 756 tU, including 49 596 tU in the measured and indicated categories.

In situ uranium resources of Tanzania (UDEPO, 2013*; company reports)

Deposit name	Resources (tU)		Grade (% U)	Estimated in	Type	Subtype	Current owner
	Measured + indicated	Inferred					
Likuyu North		2 346	0.020	2011	Sandstone	Tabular	Uranex NL
Manyoni (Bahi)	1 669	9 477	0.012	2010	Surficial	Lacustrine-playa	Uranex NL
Mtonya		775	0.022	2013	Sandstone	Tabular/ roll-front	Uranium Resources Inc.
Nyota (Mkuju River)	47 927	10 562	0.026	2013	Sandstone	Tabular	Mantra/ Uranium One

* World Distribution of Uranium Deposits (UDEPO) – https://infcis.iaea.org/UDEPO/About.

Note: The largest deposit so far is the Nyota deposit, part of the Mantra/Uranium One Mkuju River Project.

Over 80% of the total resources relate to the large Nyota sandstone-type deposit, also known as the Mkuju River Project. The systematic exploration at Nyota started in 2007 and in 2009 a maiden inferred resource estimate of 13 800 tU (35.9 Mlbs U_3O_8) and a pre-feasibility study were released. In 2011, Mantra Resources was acquired by the Russian Atomredmetzoloto and Uranium

* Report prepared by the NEA/IAEA based on previous Red Books and company reports.

One Inc. was appointed as the project operator. An update of the in situ resources of the Nyota deposit estimate in September 2011 boosted total in situ resources to 45 924 tU (119.4 Mlbs U_3O_8) and formed the basis of a feasibility study. During 2012 and 2013, Mantra Resources continued exploration focused on new resource estimates and engineering optimisation.

Drilling activities and analysis of historical data resulted in a further increase in in situ resources in June 2013 to 58 489 tU (152.1 Mlbs U_3O_8), including 124.6 Mlbs U_3O_8 (47 927 tU) in the measured and indicated categories at an average grade of 303 ppm U_3O_8 (0.0257% U). The Mkuju River feasibility study was completed in 2013 and the Tanzanian government issued a special mining licence (SML) to Mantra for project development. During 2013-2014, the main exploration activities of Mantra Resources focused on verifying Nyota deposit resources and on-site push-pull testing to identify amenability of the principal mineralisation to in situ leaching (ISL) mining.

Exploration drilling by Uranex at the Likuyu North deposit during 2009-2012 identified maiden resources of 6.1 Mlb U_3O_8 (2 346 tU) with an average grade of 237 ppm U_3O_8 (0.02% U) reported at a 100 ppm U_3O_8 (0.0085% U) cut-off grade.

In 2010, Uranex reported resources of 11 146 tU in a shallow Manyoni deposit, also known as the Bahi project. The region incorporates an extensive closed draining system developed over weathered uranium-rich granites. This drainage captures dissolved uranium leached from underlying rocks and transports it to suitable precipitation trap sites (playa lakes). The Manyoni Project encompasses up to five playa lakes.

Uranium Resources Plc in 2013 announced maiden resources of 3.6 Mt ore containing 2.014 Mlb U_3O_8 (775 tU) at a grade of 255 ppm U_3O_8 (0.00216% U) at the Mtonya deposit. The uranium mineralisation occurs at depths of 350 m in continuous 30- to 50-metre-wide roll fronts. The resource is potentially amenable to the in situ leach recovery mining method.

Recent and ongoing uranium exploration and mine development activities

After 2015, only Mantra Resources continued limited exploration activities at the Nyota deposit. During 2015-2017, exploration was focused on additional investigations to test the amenability of the ISL extraction of resources. The laboratory tests resulted in high uranium recoveries with acceptable values of uranium content in sulphuric acid solutions, acid consumption and liquid-to-solid ratio. The results of the hydrogeological test confirmed good aquifer permeability. The on-site ISL test was conducted over ten months in 2016 using a two-well pattern and the final report was issued in 2017. The results confirmed the amenability of ISL mining for the portion of the resources located below the water table. During 2017, rehabilitation of aquifers and the surface was completed after ISL tests.

In December 2016, Mantra Resources applied to the Ministry of Energy and Minerals (MEM) for a suspension of the special mining licence and the associated work programme due to the state of the uranium market, and the MEM accepted an 18-month suspension of the planned activities. During 2017-2019, further development of Mkuju River was suspended due to unfavourable uranium market conditions. In 2020, Mantra Resources decided to build a pilot processing plant during 2021-2022 and to proceed with a small-scale pilot open-pit mining operation during 2023-2025. Annual pilot plant capacity of 15 000 t of ore assumes production of 5tU/yr.

In mid-2021, Australian company Gladiator Resources Ltd agreed to acquire Zeus Resources Ltd and granted Tanzanian tenements known as the Minjingu, Mkuju, Liwale, Foxy and Eland uranium projects. Uranium resources have yet to be defined in these projects and Gladiator plans to conduct a thorough review of the project's historical data to define future exploration programmes and drill targets.

No other companies have reported uranium-related exploration activities in Tanzania since 2017.

Identified conventional resources (reasonably assured and inferred resources)

There are no changes in Tanzanian uranium resources since the previous report. Total identified in situ uranium resources from four deposits in Tanzania amount to 72 756 tU. Over 80% of the total relates to the Nyota sandstone deposit at the Mkuju River Project, which contains 47 927 tU of in situ measured and indicated resources and 10 562 tU of inferred resources, all in the

<USD 80/kgU cost category. The Manyoni playa lake calcrete deposits make up 11 146 tU of identified resources, of which 9 477 tU are inferred. The remaining inferred resources include two sandstone-type deposits: Likuju North with 2 346 tU and the Mtonya deposit, which comprises 775 tU and is potentially amenable to ISL extraction. An 80% recovery factor was applied to convert all in situ resources into recoverable resources.

Undiscovered conventional resources (prognosticated and speculative resources)

Undiscovered resources are not reported. There is, however, a high potential for sandstone-type uranium deposits in Karoo sediments in several areas of Tanzania.

Uranium production

There has been no uranium produced in Tanzania.

Future production centres

The Mkuju River feasibility study was completed in 2013 and the Tanzanian government issued an SML to Mantra for project development. Front-end engineering and design (FEED) and Pre-FEED initiatives continued until June 2014.

According to the current definitive feasibility study, the resources will be mined in multiple pits feeding a single mill with conventional acid leach and resin-in-pulp recovery. Sulphuric acid ISL mining may be employed, particularly for about 15% of resources lying outside designed pits and below the water table. One-third of the total resource is situated below the water table, so the ISL potential could be greater.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1
Name of production centre	Mkuju River
Production centre classification	Prospective
Date of first production (year)	NA
Source of ore:	
Deposit name(s)	Nyota
Deposit type(s)	Sandstone
Recoverable resources (tU)	31 700
Grade (% U)	0.0425
Mining operation:	
Type (OP/UG/ISL)	OP
Size (tonnes ore/day)	18 000
Average mining recovery (%)	90
Processing plant:	
Acid/alkaline	Acid
Type (IX/SX)	Resin-in-pulp
Size (tonnes ore/day) For ISL (mega or kilolitre/day or litre/hour, specify)	18 000
Average process recovery (%)	85
Nominal production capacity (tU/year)	3 000
Plans for expansion (yes/no)	no
Other remarks	ISL option not assumed

Activities at the project during 2015 and 2016 focused on an ISL pilot test programme. ISL could prove to be an alternative extraction method for the Mkuju River Project and similar ore bodies in the region.

In late December 2016, Mantra Resources applied to the Ministry of Energy and Minerals of Tanzania (MEM) for suspension of its SML due to the unfavourable uranium market. In September 2017, the Ministry approved an amendment to the SML, which permits construction work to start in 2020. During 2018 and 2019, Mantra Resources and MEM negotiated a further suspension of the SML. Development of the project was postponed until uranium demand increases.

Environmental activities and socio-cultural issues

The Tanzanian government has worked to allay public concerns over the prospect of uranium mining. The environmental, health, economic and social impacts are to be carefully considered and the government indicated that it is aware of the high safety standards required for uranium mining in order to protect people and the environment.

Elephant poachers have taken advantage of the road constructed for access to the Mkuju River uranium project, located in the area excised from the Selous Game Reserve. In May 2014, the operator entered into a memorandum of understanding with the Ministry of Natural Resources and Tourism to conduct combined anti-poaching initiatives. The UNESCO World Heritage Committee is monitoring the situation since all of its demands must be met in order to fulfil the Mkuju River Project requirements.

National policies relating to uranium

In 2010, the Tanzanian government substantially amended the Mining Act of 1998. The revised act increased royalty payments for mineral extraction on the gross value of minerals produced (from 3% to 5% for uranium) and mandated the government the ability to acquire shareholdings in future mining projects through a development agreement negotiated between the government and the mineral rights holder. The Parliamentary Committee for Energy and Minerals in Tanzania has directed that no mining of uranium can take place until a policy and legislation on extraction are in place.

The International Atomic Energy Agency conducted a Uranium Production Site Appraisal Team review in 2013, providing recommendations to the country, a newcomer to uranium mining, in the application of international good practices and preparations for planned uranium mining activities. The scope of the appraisal process included exploration, resource assessment, planning, environmental and social impact assessment, mining, processing, waste management, site management, remediation and final closure.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	38 342	39 677	39 677	80
Total	0	38 342	39 677	39 677	80

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	38 342	39 677	39 677	80
Total	0	38 342	39 677	39 677	80

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	38 342	38 342	38 342
Surficial	0	0	1 335	1 335
Total	0	38 342	39 677	39 677

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	8 450	17 908	17 908	80
In situ leaching acid	0	0	620	620	80
Total	0	8 450	18 528	18 528	80

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	8 450	17 908	17 908	80
In situ leaching acid	0	0	620	620	80
Total	0	8 450	18 528	18 528	80

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	8 450	10 946	10 946
Surficial	0		7 582	7 582
Total	0	8 450	18 528	18 528

Short-term production capability

(tonnes U/year)

2020				2025			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	0	0	0	0	0	0

2030				2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	0	0	0	2 000	0	2 000	0	NA	0	3 000

Türkiye

Uranium exploration and mine development

Historical background

Uranium exploration in Türkiye began in 1956-1957 and was directed towards the discovery of vein-type deposits in crystalline terrain, such as acidic igneous and metamorphic rocks. As a result of these activities, some uneconomic occurrences of pitchblende mineralisation were found. Since 1960, studies have been conducted in sedimentary rocks that surround the crystalline rocks, and some small orebodies containing autunite and torbernite mineralisation have been found in various parts of the country. In the mid-1970s, the first uranium deposit was found in the Koprubaşı area of Manisa, consisting of black coloured ore located below the water table. After 2010, the Avanos-Gülşehir and Malatya-Kuluncak uranium fields were discovered by the General Directorate of Mineral Research and Exploration (MTA). Resources increased after intensive exploration and drilling operations by the MTA and the private sector.

The state-owned organisation, General Directorate of Eti Mining Operations (Eti Maden), is responsible for the exploration and development activities of five uranium deposits with identified resources. The MTA has performed geological exploration at these sites in the past. Between 1960 and 1980, uranium exploration included aerial prospecting, general and detailed prospecting, geologic mapping and drilling. The uranium deposits were transferred from the MTA to Eti Maden as potential mines, which can be operated by the state under Law No. 2840, "Operation of Boron Salts, Trona and Asphaltite Mines and Nuclear Energy Raw Materials", issued on 10 June 1983.

Recent and ongoing uranium exploration and mine development activities

In 2017, granite, acidic igneous and sedimentary rocks around Edirne, Kırklareli, and Tekirdağ (an area of approximately 3 000 km^2) were explored for radioactive raw materials. Exploration was also performed in sites licensed by the MTA inside Nevşehir and Aydın.

In 2018, granite, acidic igneous and sedimentary rocks around Edirne, Kırklareli, and Tekirdağ (an area of approximately 3 460 km^2) were explored for radioactive raw materials. Exploration was also performed in sites licensed by the MTA in the Nevşehir and Çanakkale provinces.

In 2019, granite, acidic igneous and sedimentary rocks around the Thrace Basin (Edirne, Kırklareli and Tekirdağ provinces), Çanakkale, Nevşehir, Giresun and Aydın provinces were explored for radioactive raw materials. Drilling was conducted at sites licensed by the MTA inside the Thrace Basin, Nevşehir and Çanakkale provinces.

The MTA initiated a drilling programme to confirm previous work and develop ore resources at the Manisa-Köprübaşı exploration site. As of 11 July 2019, a total of 12 203 m of drilling had been carried out in 135 drill holes, including 2 562 m in 18 holes in 2018 and 9 641 m in 117 wells in 2019.

In 2020, granite, acidic igneous and sedimentary rocks around the Thrace Basin (Edirne, Kırklareli and Tekirdağ provinces), Çanakkale, Nevşehir, Yozgat, Giresun, Manisa and Aydın provinces were explored for radioactive raw materials. Drilling was conducted at sites licensed by the MTA inside the Thrace Basin, Nevşehir, Çanakkale, Giresun and Aydın provinces.

Eti Maden and the MTA signed a contract on 22 August 2017 for drilling exploration in Eti Maden's licensed areas to confirm resource development and to verify the previous exploration. Under this contract, 12 884 m of drilling was carried out in 149 drill holes as of 25 June 2021 in the Manisa-Köprübaşı area. In addition, 28 holes (5 446 m) and 10 holes (2 904 m) were drilled in 2020 and 2021 in the Aydın-Söke and Aydın-Nazilli areas, respectively. Also, seven holes (800 m) were drilled in 2021 in the Uşak-Eşme area. Drilling is planned to continue in the Manisa-Köprübaşı, Aydın-Söke and Aydın-Nazilli areas in 2022. The Aydın-Koçarlı area was evaluated as unpromising and abandoned through an application to the General Directorate of Mining and Petroleum Affairs.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

In 2015 and 2016, an additional 698 tU_3O_8 (592 tU) of in situ resources were added to the original estimate of the Manisa-Köprübaşı area by the MTA. In 2019, an additional 7 734 t U_3O_8 (6 559 tU) of resources were identified at the Avanos-Gülşehir deposit. These resources occur within Tertiary sediments and limestones.

As of 1 January 2021, identified in situ conventional uranium resources in Türkiye amounted to 16 736 tU (19 736 tonnes U_3O_8) including 4 340 tU of reasonably assured resources, and 12 396 tU of inferred resources. Resources are distributed in the following deposits:

- Manisa-Köprübaşı: 3 011 tU in ten orebodies and at grades of 0.04-0.05% U_3O_8 (0.034-0.042% U) in fluvial Neogene sediments;
- Uşak-Eşme: 416 tU at 0.044% U_3O_8 (0.037% U) in Neogene lacustrine sediments;
- Aydın-Koçarlı: 176 tU at 0.05% U_3O_8 (0.042% U) in Neogene sediments;
- Aydın-Söke-Nazilli: 1 466 tU at 0.08% U_3O_8 (0.068% U) in gneiss fracture zones;
- Avanos-Gülşehir: 6 559 tU at 0.05% U_3O_8 (0.042% U) in Eocene sediments.

The Yozgat/Sorgun (formerly known as Temrezli) in situ leaching (ISL) potentially amenable Eocene basal sandstone channel type uranium deposit is one of Türkiye's largest and highest-grade uranium deposits, with a mineral resource estimate of 13 282 Mlb U_3O_8 (5 108 tU) at an average grade of 0.116% U_3O_8 (0.01% U) and at an average depth of 120 m. A detailed mineral resource estimate follows:

Resource category	Tonnes	Grade (ppm U_3O_8)	Contained resources (pounds U_3O_8)	Contained resources (tonnes U)
Measured*	2 008 000	1 378	6 100 000	2 346
Indicated*	2 178 000	1 080	5 185 000	1 994
Inferred*	1 020 000	888	1 997 000	768
Total resource*	5 206 000	1 157	13 282 000	5 108

* Numbers rounded for reporting purposes.

Uranium production

Historical review

Between 1996 and 2000, research on uranium production was performed as a part of the Seventh National Development Plan of the Republic of Türkiye.

Status of production facilities, production capability, recent and ongoing activities and other issues

None reported.

Environmental activities and socio-cultural issues

Uranium exploration is assessed within the scope of Article 55 of the Annex-II list in the by-law on environmental impact assessments (EIAs) by the Ministry of Environment, Urbanisation and Climate Change. Mine production activities for 25 ha and above, together with the mine enrichment activities, are evaluated within the scope of the Annex-I list of the EIA by-law.

Regulatory regime

The Nuclear Regulatory Authority (NDK), as the regulatory authority of Türkiye, undertakes regulatory activities concerning facilities, including nuclear power plants, devices, substances, and activities related to nuclear energy and ionising radiation. The NDK was established by a decree having the force of Law No. 702 dated 2 July 2018 as an independent authority associated with the Ministry of Energy and Natural Resources (MENR).

In Türkiye, nuclear installations are licensed by the NDK regarding nuclear safety, security and radiological protection issues. Before the NDK, the Turkish Atomic Energy Authority (TAEK) was the licensing authority according to Law No. 2690, which regulated the duties and responsibilities of TAEK as a regulatory body.

The NDK was founded in July 2018, with the Decree of Law No. 702, and became the regulatory authority of Türkiye. Within the same month, Presidential Decree No. 4 dated 15 July 2018, came into force. The duties and responsibilities of the NDK were determined and TAEK was reorganised as a research and development and technical support service organisation. In 2020, the Turkish Energy, Nuclear and Mineral Research Authority (TENMAK) was founded as an affiliate to the Ministry of Energy and Natural Resources with Presidential Decrees No. 4 and 57 by incorporating three governmental institutions related to nuclear, boron and rare earth elements research (named as TAEK, BOREN and NATEN respectively). The Nuclear Energy Research Institute (NUKEN) was established within TENMAK to carry out studies on nuclear science and technologies. Nuclear fuel cycle research and fuel development studies are conducted on a laboratory scale within the Istanbul campus of NUKEN.

As a part of the transition process, the NDK will issue new regulations according to the new licensing system. For the time being, the authorisation process of nuclear installations will continue as follows:

- The existing authorisation applications will be concluded following the provisions of the legislation in force (decrees, regulations, etc.) until the new regulations are issued according to Decree Law No. 702. In this context, the implementation of the Decree on Licensing of Nuclear Installations, which is the main legislation used for licensing, will continue. The references to TAEK in the applicable legislation are deemed to have been made to the NDK.
- The licensing procedure for nuclear fuel cycle facilities is laid out in the Decree on Licensing of Nuclear Installations. According to this decree, nuclear fuel cycle facilities are:
  - mining, milling, and refining facilities;
  - conversion facilities;
  - enrichment facilities;
  - nuclear fuel element fabrication facilities;
  - reprocessing facilities for used fuel elements;
  - radioactive waste management facilities for processing radioactive waste (including final storage).

The licensing procedure for nuclear fuel cycle facilities is initiated by an application from the owner. The licensing process comprises three main stages in succession: site licence, construction licence and operating licence. There are several permits required during the licensing process, such as a limited work permit, a permit to start test operations, a pre-operational test permit, a full capacity work permit, permission to restart operations and permission to modify the installation. For each authorisation, the documents required for review and assessment by the NDK are defined in the decree.

Uranium requirements

There are no nuclear power plants in operation or decommissioning activities underway. However, three reactor units are under construction in Türkiye. Türkiye has considered building a nuclear power plant since the 1970s. Rising energy demand, import dependence, and industrial activity are the driving forces behind Türkiye's move towards developing a civil nuclear power generation programme. Türkiye's recent efforts in this area can be characterised as a first-of-a-kind approach in the nuclear sector and have been referred to as an intergovernmental agreement (IGA) model, with long-term contracts of power purchase agreements. In this approach, a project company undertakes to design, build, operate and maintain a power plant, whereas the Turkish government is responsible for providing the site, various financial and non-financial guarantees, construction support, and licensing. The project company is also responsible for managing wastes and decommissioning the facility.

The construction and operation of a nuclear power plant, through a co-operation agreement between the government of Russia and the government of Türkiye, is being carried out at Akkuyu, Mersin Province, Türkiye. The Akkuyu Nuclear Power Plant project plans for the construction of four VVER-1200 reactors with a total capacity of 4 800 MWe.

Under the construction schedule, the following dates are planned for the commissioning of the Akkuyu Nuclear Power Plant power units into operation:

- Unit No l – 2023;
- Unit No 2 – 2024;
- Unit No 3 – 2025;
- Unit No 4 – 2026.

Türkiye also signed a memorandum of understanding with Japan on 3 May 2013 to build four ATMEA1 units at the Black Sea Sinop site. The technical and economic feasibility studies for the Sinop Nuclear Power Plant were completed in July 2018 and submitted to the MENR for evaluation. After a detailed evaluation of the Feasibility Report, Türkiye decided not to continue the Sinop Nuclear Power Plant project with Japan.

Supply and procurement strategy

According to Article 12 of the agreement between the government of Russia and the government of Türkiye on co-operation in the construction and operation of the Akkuyu Nuclear Power Plant, nuclear fuel will be sourced from suppliers based on long-term agreements entered into between the project company and the suppliers. The Akkuyu Nuclear Joint-Stock Company is planning to secure a supply of nuclear fuel from TVEL, a subsidiary of Rosatom.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The law on the "Operation of Boron Salts, Trona and Asphaltite Mines and Nuclear Energy Raw Materials" No. 2840, dated 10 June 1983, states that exploration and mine operations are to be carried out by the state.

Uranium stocks

TENMAK-NUKEN holds natural uranium stocks in different forms for research activities.

Uranium exploration and development expenditures and drilling effort – domestic

(TRY [Turkish lira] – excluding VAT)

	2019	2020
Government exploration expenditures	82 193 522	49 919 630
Total expenditures	82 193 522	49 919 630
Government exploration drilling (m)	198 613	193 329
Government exploration holes drilled	484	576
Total drilling (m)	198 613	193 329
Total number of holes drilled	484	576

Reasonably assured resources by production and processing method

(in situ tonnes U)

Production method	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
ISL	0	4 340	4 340
Total	0	4 340	4 340

Reasonably assured resources by deposit type

(in situ tonnes U)

Deposit type	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	4 340	4 340
Total	0	4 340	4 340

Inferred resources by production and processing method

(in situ tonnes U)

Production method	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional OP	0	10 162	10 162
ISL	0	768	768
Unspecified	0	0	1 466
Total	0	10 930	12 396

Inferred resources by deposit type

(in situ tonnes U)

Production method	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	4 371	4 371
Metamorphite	0	0	1 466
Carbonate	0	6 559	6 559
Total	0	10 930	12 396

Installed nuclear generating capacity to 2035

(MWe net)

2019		2020		2025		2030		2035	
Low	High	Low	High	Low	High	Low	High	Low	High
0	0	0	0	1 200	2 400	4 800	4 800	4 800	4 800

Annual reactor-related uranium requirements to 2035 (excluding MOX)

(tonnes U)

2019		2020		2025		2030		2035	
Low	High	Low	High	Low	High	Low	High	Low	High
0	0	0	0	190	380	720	720	720	720

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	4.1	0	0	0	4.1
Total	4.1	0	0	0	4.1

Ukraine

Uranium exploration and mine development

Historical review

Prospecting for uranium in Ukraine began in 1944 with the analysis of geological exploration data and mining activity results in the Northern Kryvyy Rig ore basin. The Pervomayske and Zhovtorechenske uranium deposits were discovered in the 1950s. These deposits were mined out in 1967 and 1989, respectively. During the same period, the first sandstone-type deposits were discovered.

In the mid-1960s, the main geological exploration was concentrated in the Kirovograd ore area for the discovery of metasomatite-type uranium deposits. Deposits such as Michurinske, Vatutinske, Severinske, Central and Novokostyantynivske were discovered in this area.

Metasomatite-type deposits make up the main part of uranium resources of Ukraine. The average ore grade in these deposits is 0.1-0.2% U. The second uranium resource source is sandstone-type deposits, with an average ore grade between 0.02 and 0.06% U. They are suitable for mining by in situ leaching (ISL).

Ongoing uranium exploration and mine development activities

During 2019-2021, State Enterprise "Kirovgeology" undertook analytical work on existing geological data to identify areas perspective for uranium exploration. Since 2019, all exploration on sandstone-type uranium deposits has been carried out by a private company. In 2018, a Ukrainian private company obtained licences for exploration of the Safonivske, Surske, Novogurivske and Mikhaylivske uranium deposits and carried out exploration activities on them. Ukrainian companies do not carry out any exploration for uranium in other countries.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2021, identified uranium resources (reasonably assured and inferred resources) recoverable at costs <USD 260/kgU were 185 389 tU. Uranium resources recoverable at costs <USD 80/kgU were 71 841 tU. Mining and processing losses are considered in these scenarios.

The main uranium resources of economic interest are found in two types of deposits:

- Metasomatite-type, monometallic deposits located within the Kirovograd block of the Ukrainian Shield. The uranium ore grade is 0.1-0.2% U. All deposits are suitable for underground mining.
- Sandstone-type deposits located within the Dnieper-Bug metallogenic area (17.3 thousand km^2). The uranium ore grade is 0.02-0.06% U. In addition to uranium, molybdenum, selenium and rare earth elements of the lanthanide group occur in these ores. These deposits are suitable for mining by ISL.

Undiscovered resources (prognosticated and speculative resources)

Undiscovered in situ uranium resources amount to 277 500 tU, including:

- Prognosticated resources of 22 500 tU situated on the flanks of identified deposits.
- Speculative resources of 255 000 tU, based on the data from the uranium prognostic map (scale of 1:500 000), which was created by SE "Kirovgeology". Speculative resources are subdivided according to geological types as follows:
  - 133 500 tU metasomatite-type;
  - 20 000 tU in sandstone deposits on the Ukrainian Shield;
  - 16 500 tU in sandstone (in bitumen) on the slopes of the Ukrainian Shield;
  - 40 000 tU in "unconformity-related" type deposits;
  - 30 000 tU in granite-related type deposits;
  - 15 000 tU in "intrusive" potassium metasomatite deposits.

Unconventional resources and other materials

Thorium speculative resources are estimated at 251 669 t, 60% of which relate to the metasomatite deposit type. The evaluation of potential thorium resources in the Ukrainian Shield rocks will continue.

Ukraine thorium speculative resources by deposit types

(in situ tonnes Th)

Deposit type	Resources tTh (in situ)
Granite-related	53 940
Alkaline rocks	37 037
Metasomatite	150 439
Metamorphite	10 253
Total	251 669

Uranium production

Historical review

Uranium mining began in 1946 at the Pervomayske and Zhovtorechenske deposits using conventional underground methods. In 1949, the first uranium production began at the Pridniprovskyy Chemical Plant (PCP), in the town of Dniprodzerzhinsk (now Kamyanske).

In 1951, the government founded the State Enterprise "Eastern Ore Dressing Complex" (VostGOK) in Zhovti Vody in the Dnipropetrovsk region for the mining and processing of ore from the Pervomayske and Zhovtorechenske deposits. In 1959, a second uranium processing plant was built in Zhovti Vody. The Pervomayske deposit was mined out in 1967 and the Zhovtorechenske deposit was mined out in 1989.

ISL uranium mining began in Ukraine in 1961. From 1966 to 1983, uranium from the Devladovske and Bratske deposits was recovered by the sulphuric acid ISL method at a depth of about 100 m. At present, aquifers of both deposits are undergoing monitoring.

Status of production facilities, production capability, recent and ongoing activities and other issues

VostGOK operates four underground mining units: Michurinske (3 km south of Kropyvnytskyy; formerly Kirovograd), Tcentralne (on the south-east end of Kropyvnytskyy), Vatutinske (near the town of Smolino) and Novokostyantynivske (40 km west of Kropyvnytskyy).

Hydrometallurgical processing plant

The VostGOK hydrometallurgical processing plant is situated in the town of Zhovti Vody. The annual capacity of the plant is 1.5 Mt of ore. Each plant shift employs 30 to 35 people. Uranium ore is transported to the plant by specially equipped trains from the Ingulska (100 km west) and Novokostyantynivska (130 km west) mines, and by trucks from the local Smolinska mine.

Uranium production method

Metasomatite-type deposits in Ukraine have a uranium ore grade of about 0.1% U, with disseminated mineralisation (uraninite, brannerite, coffinite, pitchblende) throughout the steeply dipping ore bodies. Mining is carried out by the underground method. Processing of mined ore begins with crushing, followed with extraction by sulphuric acid leaching in autoclaves at the hydrometallurgical processing plant. Low-grade uranium ore, combined with expensive underground mining technology, processing technology and transportation (mines are located some 100 km and 130 km from the processing plant), combine to create high production costs, compared to current market prices. To decrease production costs, innovative technologies, such as underground radiometric sorting, in-place leaching, heap leaching and reprocessing of materials in dumps of operating mines are being introduced.

A multistage radiometric separator, designed by VostGOK for different sized piles, allows sorting of both mined ore and material in mine dumps. After the radiometric sorting, the uranium content in the ore may reach 0.03-0.3% U. The uranium content in tailings after radiometric sorting is 0.006% U or less.

After crushing, uranium ore undergoes heap leaching (HL) at the Vatutinske deposit, with a recovery factor of about 82-83%. The uranium production cost of HL is 15% lower than at the hydrometallurgical processing plant.

Although most metasomatite-type ore deposits are suitable for HL, additional ore treatment for effective HL is necessary, since the degree of crushing and permeability are the most important parameters that determine uranium recovery. The maximum size of uranium mineral particles is usually from 1 to 5 mm. With an optimum size of ore material of 10 mm, 80-90% uranium recovery can be achieved after 2-3 months of leaching.

Heaps contain ore grades of 0.050-0.080% U as a result of radiometric sorting. The volume of the heap is 40 000 t of ore. At the Vatutinske deposit, four heaps with a total volume of 160 Kt of ore have been built. At the Michurinske deposit, HL is planned.

Uranium production centres technical details

(as of 1 January 2021)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5
Name of production centre	Ingulska mine	Smolinska mine	Novokostyantynivska mine	Safonivska mine	Severinska mine
Production centre classification	Existing	Existing	Existing	Planned	Planned
Date of first production (year)	1968	1973	2011	2023	N/A
Source of ore:					
Deposit name(s)	Michyrinske, Tsentralne	Vatutinske	Novokostyantynivske	Safonivske	Severinskie Podgaytsevske
Deposit type(s)	Metasomatic	Metasomatic	Metasomatic	Sandstone	Metasomatic
Recoverable resources (tU)	51 810	1 577	79 830	2 248	45 060
Grade (% U)	0.1	0.11	0.14	0.02	0.1
Mining operation:					
Type (OP/UG/ISL)	UG	UG	UG	ISL	UG
Size (tonnes ore/day)	2 000	2 000	6 000	N/A	4 200
Average mining recovery (%)	95	96	96	75	96
Processing plant:					
Acid/alkaline	Acid	Acid	Acid	Acid	Acid
Type (IX/SX)	IX	IX	IX	IX	IX
Size (tonnes ore/day) For ISL (mega or kilolitre/day or litre/hour)	N/A	N/A	N/A	20 000 kilolitre/day	N/A
Average process recovery (%)	93	94	94	95	92
Nominal production capacity (tU/year)	450	500	1 500	150	1 200
Plans for expansion (yes/no)	Yes	No	No	No	No

Ownership of uranium industry

Almost all enterprises in the Ukrainian uranium industry (geology, mining, processing) are owned by the state. The state enterprise “VostGOK” (“Eastern Ore Dressing Complex”) belongs to the Ministry of Energy of Ukraine. State Enterprise “Kirovgeology” is responsible for geological surveys, resource evaluations and exploration of deposits in Ukraine. It is part of the State Service of Geology and Resources of Ukraine, in the Ministry of Ecology and Natural Resources.

In April 2008, the government of Ukraine founded the state concern “Nuclear Fuel” through the merger of existing companies in the sphere of the uranium mining, processing, designing and fuel manufacturing.

Secondary sources of uranium

- Mixed oxide fuel (MOX) has never been produced in Ukraine or used in its nuclear power plants;
- Re-enriched tails have never been produced or used in Ukraine;
- Reprocessed spent nuclear fuel is not produced or used in Ukraine.

Environmental activities and socio-cultural issues

The main environmental impacts of uranium production at mines come from ore stockpiles, tailings, radiometric ore-sorting sites, waste dumps, ventilation systems infrastructure and transport (railways, technological motor roads).

The main environmental impacts from the hydrometallurgical process plant and heap leaching sites are harmful chemical and ore dust emissions, airborne transportation of aerosols and groundwater contamination from tailings impoundments. Permanent monitoring is conducted to control the environmental impacts.

In the hydrometallurgical plant (Zhovti Vody), process water is recycled for the technological process. There are two tailings impoundments, one situated 9 km from the hydrometallurgical plant consisting of two sections (614.9 ha containing 45.346 Mt of waste) with total activity of $455.68 \cdot 10^{12}$ Bq, and the second 0.5 km from the plant (55 ha containing 16 Mt of waste) with total activity of $93.3 \cdot 10^{12}$ Bq. The latter is no longer used, and reclamation is ongoing.

There are also issues connected with the decommissioning of uranium mining and uranium processing enterprises.

At the closed Prydniprovskyy Chemical Plant, there are nine tailings impoundments (covering a total area of 268 ha containing 42 Mt of waste) with total activity of $2\,775 \cdot 10^{12}$ Bq and some buildings and other facilities are contaminated by radioactive elements. The Cabinet of Ministers of Ukraine has had a state programme for reclamation with state funds amounting to USD 4.5 million since 2005.

The total cost of improving radiological protection across all enterprises in the nuclear industry and all contaminated areas resulting from mining and processing of uranium is expected to amount to USD 360 million, including decontamination of polluted soils, environmental monitoring, installation of monitoring systems where necessary and improved technology for the management of water flows, radioactive rocks in dumps, polluted equipment and land areas.

Uranium requirements

Uranium production in Ukraine meets 30% of domestic nuclear energy requirements. As of 1 January 2021, nuclear fuel requirements have always been provided by importing fuel from Russia (provided by TVEL). Annual fuel loadings of the 4 operating nuclear power plants (comprised of 13 VVER-1000 units and 2 VVER-440 units) are 15 sets of fuel elements at a total cost of about USD 500 million. The “Energy Strategy of Ukraine to 2035”, which was approved by the government in 2017, set a target that uranium requirements for the Ukrainian nuclear reactors be met by domestic production.

Installed nuclear generating capacity by 2035

At present, 15 reactors are operating at 4 nuclear power plants: 6 VVER-1000 units at Zaporizhzhia, 3 VVER-1000 units at South-Ukrainian, 2 VVER-1000 and 2 VVER-400 units at Rovenskyy and 2 VVER-1000 units at Khmelnitskyy.

Implementation of the national programme for nuclear energy development to 2030 will involve increasing installed capacity of nuclear energy up to 29.5 MWe. To meet this target, annual nuclear energy production will have to increase to 75.2 GWe/h. This will require a life extension for operating nuclear power plants, the construction of 12 additional units (with total capacity of 15 000 MWe) and during this time frame, the decommissioning of 12 nuclear power plants that will reach the end of their operational lifetime. In 2021 this programme was under government review.

Uranium policy, uranium stock and uranium price

In 2017, the Ukrainian government approved the "Energy Strategy of Ukraine to 2035". Ukraine views nuclear generation as economic and carbon-free energy and plans to increase the nuclear energy portion in the total balance up to 2035. This serves as a background for uranium policy.

The Ukrainian government's uranium policy includes the following goals:

- improve the uranium resource base through the exploration of new uranium deposits;
- increase uranium production by mining existing uranium deposits;
- extend the range of components that Ukraine manufactures for nuclear fuel assemblies;
- create a stock of uranium concentrate (U_3O_8);
- diversify nuclear fuel supply.

On 17 April 2009, the Cabinet of Ministers of Ukraine founded the State Concern "Nuclear Fuel", through the merger of all state enterprises and research and design institutes in the field of nuclear fuel. The task of the Concern is to co-ordinate the company's activity for the construction of a nuclear fuel plant.

The "Private Joint Stock Company Nuclear Fuel Fabrication Plant" for nuclear reactors of the VVER-1000 type was established in Ukraine in October 2011. The plant is situated in the Kirovograd region, close to the "Vatutinske" uranium deposits. In the JSC, a 50.000006% share belongs to State Concern "Nuclear Fuel" and a 49.999994% share to the state Russian company TVEL, as of 2021.

The technical economic assessment for construction of the plant was approved by the Cabinet of Ministers of Ukraine (statement N437 dated 27 June 2012). The total cost of construction is estimated at about USD 80 million, according to a new estimate made by the Ministry. Planned capacity of the plant is 800 nuclear fuel sets per year. However, the construction of the plant has been postponed.

Uranium exploration and development expenditures and drilling efforts – domestic

(UAH million as of 1 January 2021)

	2019	2020	2021 (expected)
Industry* exploration expenditures	0	0	0
Government exploration expenditures	5.8	1.9	8.0
Industry* development expenditures	39.3	24.4	70.0
Government development expenditures	13.4	21.1	16.4
Total expenditures	58.5	47.4	94.4
Industry* exploration drilling (m)	0	0	N/A
Industry* exploration holes drilled	0	0	N/A
Government exploration drilling (m)	601	0	1 485
Government exploration holes drilled	2	0	18
Industry* development drilling (m)	0	0	0
Industry* development holes drilled	0	0	0
Government development drilling (m)	10 524	12 740	9 710
Government development holes drilled	624	688	561
Subtotal exploration drilling (m)	601	0	1 485
Subtotal exploration holes drilled	2	0	18
Subtotal development drilling (m)	10 524	12 740	9 710
Subtotal development holes drilled	624	688	561
Total drilling (m)	11 125	12 740	11 195
Total number of holes drilled	626	688	579

* Non-government.

A decision was taken to build a central storage facility for used fuel from domestic VVER reactors in the Chernobyl exclusion zone (Law of Ukraine N4384, dated 2 September 2012). Initially, the commissioning was planned for 2016. In December 2020, the first storage facility was opened together with the construction company "Holtec International" of the United States.

In September 2012, the decision to build two nuclear power plants, N3 and N4 on the Khmelnitsky site, in collaboration with Russia was made (the Law of Ukraine N4384 dated 2 September 2012). Commissioning of these units was initially set for 2018 (N3), and 2020 (N4), respectively. However, in 2015 the new build activities were postponed.

At present "ENERGOATOM", the Ukrainian nuclear generation company, is in discussions on the construction of new reactors.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining	0	41 437	69 625	116 867	88.4
In situ leaching acid	0	3 718	3 718	3 718	75.0
Total	0	45 155	73 343	120 585	

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	41 437	69 625	116 867	88.4
In situ leaching acid	0	3 718	3 718	3 718	75.0
Total	0	45 155	73 343	120 585	

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposits type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	3 718	3 718	3 718
Metasomatite	0	41 437	69 625	116 867
Total	0	45 155	73 343	120 585

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining	0	26 284	33 416	60 652	88.7
In situ leaching acid	0	402	402	4 152	75.0
Total	0	26 686	33 818	64 804	

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	26 284	33 416	60 652	88.7
In situ leaching acid	0	402	402	4 152	75.0
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Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	0	402	402	4 152	75.0
Metasomatite	0	26 284	33 416	60 652	88.4
Total		26 686	33 818	64 804	

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	8 400	22 500

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	120 000	255 000

Historical uranium production by production method

(tonnes U in concentrate)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining*	10 000	0	0	10 000	0
Underground mining*	109 008	796	711	110 515	455
In situ leaching	3 925	0	0	3 925	0
Co-product/by-product	10 000	0	0	10 000	0
Total	132 933	796	711	134 440	455

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrate)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	128 732	721	623	130 076	405
In situ leaching	3 925			3 925	0
In-place leaching*	26	0	0	26	0
Heap leaching**	250	75	88	413	50
Total	132 933	796	711	134 440	455

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposits type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Sandstone	3 925	0	0	3 925	0
Granite-related	35 000	0	0	35 000	0
Metasomatite	94 008	796	711	95 515	455
Total	132 933	796	711	134 440	455

Ownership of uranium production in 2020

Domestic				Abroad				Total	
Government		Private		Government		Private			
(t U)	(%)	(t U)	(%)	(t U)	(%)	(t U)	(%)	(t U)	(%)
711	100	0	0	0	0	0	0	711	100

Uranium industry employment at existing production centres

(persons/years)

	2019	2020	2021 (expected)
Total employment at existing production centres	3 701	3 741	3 829
Direct employment at uranium production	1 288	1 302	1 332

Mid-term production projections (tonnes U/year)

2021	2022	2025	2030	2035	2040
455	750	1 000	1 500	1 500	2000

Mid-term production capability (tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
N/A	N/A	1 000	1 200	N/A	N/A	1 500	1 700
2035				**2040**			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
N/A	N/A	1 500	1 700	N/A	N/A	N/A	N/A

Net nuclear electricity generation

	2019	2020
Net nuclear electricity generation (TWh net)	83.0	76.2

Installed nuclear generating capacity to 2040

(GWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
13.8	13.8	13.8	13.8	16.5	20.2	18.8	26.2	26.0	30.5

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
2 480	2 480	2 480	2 480	3 020	3 660	3 600	4 800	4 800	5 300

United States

Uranium exploration and mine development

Historical review

From 1947 through 1970, the US government fostered a domestic private sector uranium exploration and production industry to procure uranium for military uses and to promote research and development in peaceful atomic energy applications. By late 1957, both the number of new deposits that private industry brought into production and production capability had increased sufficiently to meet projected requirements. Federal exploration programmes ended at that time.

Private exploration by the US uranium industry increased throughout the 1970s in response to rising prices and the projected high demand for uranium to fuel an increasing number of nuclear reactors under construction or planned for construction to power civilian electric generation stations. Total annual surface drilling peaked in 1978.

Exploration has been primarily for sandstone-type uranium deposits in districts such as the Grants Mineral Belt and Uravan Mineral Belt of the Colorado Plateau, the Wyoming basins, and the Texas Gulf Coastal Plain region.

Recent and ongoing uranium exploration and mine development activities

In 2019 and 2020, the uranium industry in the United States continued to contract uranium requirements from non-domestic sources, leading to historically low levels of domestic exploration and production. Decreases in drilling, production and related expenditures are due in large part to a global oversupply of uranium and the resulting low uranium prices. These continued low prices have significantly affected the domestic mining industry. Private companies that explore for and produce uranium in the United States have been reducing expenditures to minimal levels to retain property holdings and infrastructure in hopes of a potential price increase.

Mine owners are also looking to extract mining co-products, such as vanadium and copper, to improve the economics of their mines. The only operating conventional uranium mill, the White Mesa Mill in Utah, has added additional capabilities, such as extracting rare earth elements from black sands and processing alternative feed material, to remain viable. In addition to reducing production-related activities, environmental requirements and costs are increasing as the United States works to remediate legacy mining impacts. Federal regulators and land use agencies usually lead these remediation efforts, which are funded by significant financial contributions by previous mining companies through legal judgements.

From a recent peak of USD 352.9 million in 2012, US uranium expenditures decreased by 75% to USD 87 million in 2020. In 2020, expenditures on US uranium production, including facility expenses, were USD 40 million, down 82% from a recent peak of USD 221.2 million in 2008. Industry activity has declined to levels that require significant amounts of data to be withheld to avoid disclosure of individual company data.

The trend of decreasing drilling that began in 2013 continued through the latest data made publicly available in 2017. The US Energy Information Administration (EIA) could not disclose drilling activity from 2018 through 2020.

United States uranium expenditures, 2008-2020

(USD million)

Year	Drilling	Production	Land and other				Total expenditures
			Total land and other	Land	Exploration	Reclamation	
2008	81.9	221.2	164.4	65.2	50.2	49.1	467.6
2009	35.4	141.0	104.0	17.3	24.2	62.4	280.5
2010	44.6	133.3	99.5	20.2	34.5	44.7	277.3
2011	53.6	168.8	96.8	19.6	43.5	33.7	319.2
2012	66.6	186.9	99.4	16.8	33.3	49.3	352.9
2013	49.9	168.2	90.6	14.6	21.6	54.4	308.7
2014	28.2	137.6	74.0	11.6	10.7	51.7	239.7
2015	28.7	118.5	76.2	12.1	4.7	59.4	223.5
2016	22.3	98.0	49.6	9.9	2.5	37.2	169.9
2017	4.0	78.3	40.3	8.9	3.7	27.7	122.6
2018	W	65.9	W	W	W	W	108.8
2019	W	38.0	W	W	W	W	81.0
2020	W	40.0	W	W	W	W	87.0

Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 8.

Notes: Expenditures are in nominal USD. Totals may not equal sum of components because of independent rounding.

W = Data withheld to avoid disclosure of individual company data. Drilling = All expenditures directly associated with exploration and development drilling. Production = All expenditures for mining, milling, processing of uranium and facility expense. Total land and other = All expenditures for land; geological research; geochemical and geophysical surveys; costs incurred by field personnel during exploration, reclamation, and restoration work; and overhead and administrative charges directly associated with supervising and supporting field activities.

United States uranium drilling activities, 2008-2020

Year	Exploration drilling		Development drilling		Exploration and development drilling	
	Number of holes	Metres (thousand)	Number of holes	Metres (thousand)	Number of holes	Metres (thousand)
2008	5 198	775	4 157	778	9 355	1 552
2009	1 790	320	3 889	820	5 679	1 141
2010	2 439	445	4 770	1 050	7 209	1 495
2011	5 441	1 013	5 156	915	10 597	1 928
2012	5 112	1 051	5 970	1 131	11 082	2 181
2013	1 231	280	4 013	892	5 244	1 172
2014	W	W	W	W	1 752	396
2015	W	W	W	W	1 518	268
2016	W	W	W	W	1 158	231
2017	W	W	W	W	420	60
2018	W	W	W	W	W	W
2019	W	W	W	W	W	W
2020	W	W	W	W	W	W

Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 1.

Note: Totals may not equal sum of components because of independent rounding. W = Data withheld to avoid disclosure of individual company data.

Conventional and in situ recovery mine development

At the end of 2020, two US uranium in situ recovery (ISR) plants were operating with a combined capacity of 7.5 million pounds of uranium oxide (U_3O_8) (2 900 tU) per year (the Lost Creek Project and the Smith Ranch-Highland Operation in Wyoming). Nine ISR plants were on standby at the end of 2020, and nine ISR plants were planned across four states: New Mexico, South Dakota, Texas and Wyoming.

The United States has several conventional and ISR-amenable mines and deposits with some degree of permitting or development. Most of these are indefinitely paused, awaiting more favourable market conditions. ISR mining and exploration is mostly in Texas and Wyoming, and conventional mine-related activity is in the part of the Colorado Plateau that includes Colorado, Utah, New Mexico and Arizona. Although not a comprehensive review of the status of these uranium mines and properties, significant activities or developments during 2019 and 2020 are described below. Developments ancillary to the uranium production, such as property transfers, incremental permitting, and financial actions, are not included.

Colorado

- La Sal Complex (conventional underground – Energy Fuels Inc.): In 2019, 5 200 feet (1 600 m) of underground drilling was completed and 30 surface exploration holes were drilled. This drill programme followed rehabilitation of the La Sal and Pandora declines, vent raises, main haulage and working areas, and a test-mining programme that primarily focused on the vanadium resource at this uranium-vanadium mine complex.
- Sunday Mine Complex (conventional underground – Western Uranium and Vanadium Corporation): In 2020, Western Uranium rehabilitated some underground workings and began production primarily to beneficiate vanadium that occurs with uranium in this deposit. The company encountered regulatory issues that delayed ore shipment, and mining remains on standby status.

New Mexico

- Mt. Taylor mine (conventional underground – Rio Grande Resources): A plan to close the mine was submitted to New Mexico in 2019. Commercial production began at Mt. Taylor in 1989 from a mineralised zone about 900 metres below the surface that contains one of the largest known uranium resources in the United States (~38 000 metric tonnes of uranium [tU] historical resource). However, the mine has been on standby status since 1999, and the public has pressured the state to discontinue ongoing extensions of this status.

South Dakota

- Dewey Burdock (ISR – Azarga Uranium): Azarga completed federal permitting and released an updated Preliminary Economic Assessment and mineral resource estimate of about 6 500 tU in the measured and indicated categories.

Texas

- Burke Hollow (ISR – Uranium Energy Corporation): In 2019, UEC received the last of four major permits required to mine the deposit, and it embarked on a 57-hole drill programme to explore and delineate the deposit as well as construct monitoring wells it will use during mining.

Wyoming

- Lance Project (ISR – Peninsula Energy Ltd): Peninsula Energy Ltd received approval for a low pH (acid) mining field demonstration in previously mined wellfields in 2019. Acid mining has not been approved for any commercial-scale ISR mine in the United States because of concerns about groundwater restoration.
- Reno Creek (ISR – Uranium Energy Corporation [UEC]): In 2019, UEC reported an updated NI 43-101 resource estimate of about 10 000 tU in the measured and indicated categories.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

At the end of 2020, estimated uranium reserves (in situ reasonably assured resources [RAR]) were 12 000 tU at a maximum forward cost of less than USD 80 per kilogram of uranium (kgU). At a cost of less than USD 130/kgU, estimated reserves were 79 231 tU. At a cost of less than USD 260/kgU, estimated reserves were 149 538 tU. Private companies prepare these estimates of uranium resources. These estimates change each year due to production (resource depletion), changes in resource estimation, site boundary expansions and evolving production costs. Industry participants prepare the uranium resource estimates and report them to the US Energy Information Administration (EIA), which aliases the resources by tabulating them into states or regions without further analysis.

Reserve estimates were available for 68 properties at the end of 2020. Current estimates of uranium reserves cannot be compared with the much larger historical data set of uranium reserves published in the July 2010 US Department of Energy (DOE) report, *U.S. Uranium Reserves Estimates*. The EIA made those estimates based on data it had collected and data developed by the National Uranium Resource Evaluation (NURE) programme, operated out of Grand Junction, Colorado, by the DOE and predecessor organisations. The EIA data covered approximately 200 uranium properties with reserve estimates collected from 1984 through 2002. The NURE data covered approximately 800 uranium properties with reserve estimates collected from 1974 through 1983. Although the 2014 data collected on the Form EIA-851A survey, Domestic Uranium Production Report (Annual), cover a much smaller set of properties than the earlier EIA and NURE data, the EIA believes that, within its scope, the EIA-851A survey data provide more reliable estimates of the uranium recoverable at the specified forward cost than estimates derived from 1974 through 2002. In particular, the NURE data have not been comprehensively updated in many years and are no longer considered a current data source.

The United States has not historically reported inferred resources. In 2014, the United States began an evaluation of the relative importance of the inferred resource category available in published estimates of US uranium properties. Based on this limited analysis, uranium resources for the United States would likely increase minimally, by 10%, if inferred resources were tabulated in addition to reasonably assured resources. Recognising the limited information available and the importance of this class of resource, the United States is considering which mechanisms for collecting inferred uranium resource data would be the most viable.

Undiscovered conventional resources (prognosticated and speculative resources)

Prognosticated and speculative uranium resources for the United States were last comprehensively assessed in 1980. The US Geological Survey (USGS) is now re-estimating undiscovered resources for the United States using the USGS three-part method of quantitative undiscovered mineral resource assessment. Estimates for various regions and deposit types have been prioritised and are ongoing. Two assessments have been completed, estimating mean undiscovered resources of about 85 000 tU recoverable in the Texas Coastal Plain and 15 400 tU in situ in the Southern High Plains region.[*] The different estimates for in situ versus recoverable uranium is a result of the different grade and tonnage models used for the estimates (one where in situ uranium data were available; the other where only recovered uranium data were available). The USGS methodology used to estimate undiscovered resources produces probabilistic estimates of potential resources, but these estimates are not in cost categories. Therefore, these estimates are not included in undiscovered resource compilations elsewhere in this report.

* For details of the undiscovered resource assessments for the United States see: Hall, S., et al. (2017), "Assessment of undiscovered resources in calcrete uranium deposits, Southern High Plains region of Texas, New Mexico and Oklahoma, 2017", US Geological Survey Fact Sheet 2017-3078: 2 p; and Mihalasky, M. J., et al. (2015), "Assessment of undiscovered sandstone-hosted uranium resources in the Texas Coastal Plain, 2015", US Geological Survey Fact Sheet 2015-3069: 4p.

A deposit model was completed for the Coles Hill Deposit in Virginia in 2020 as part of what was to be the next planned assessment of undiscovered resources in the southern Appalachia region. Another deposit model is in development for the Colorado Plateau region. These models are used to help identify additional concealed deposits in addition to informing undiscovered resource assessments. Although only about 10% of the undiscovered uranium resources in the United States have been assessed, future assessments are not scheduled due to staffing shortfalls at the US Geological Survey.

US undiscovered uranium resource assessments, 2015-2020

Tract name	Age	Sub-tract	Permissive area (km²)	N_{known}	N_{und}	Probability of at least the indicated amount of undiscovered tU			Mean undiscovered resources (tU)
						0.9	0.5	0.1	
Southern High Plains (TX, NM, OK)	Pliocene to Pleistocene	North	43 920	0	1.1	0	1 600	10 200	3 500
		South	46 630	2	3.9	3 100	10 200	22 900	11 900
Totals – Southern High Plains (in situ tU)			90 550	2	5.0				15 400
Texas Coastal Plain – Claiborne-Jackson	Eocene	Rio Grande Embayment	38 460	18	27	5 000	18 500	38 100	20 400
		Houston Embayment	62 670	1	3	100	1 800	5 400	2 500
Texas Coastal Plain – Catahoula-Oakville TX	Oligocene to Miocene	Rio Grande Embayment	14 220	35	41	11 200	30 400	50 000	31 500
		Houston Embayment	16 710	0	3	100	1 900	5 400	2 500
Texas Coastal Plain – Goliad-Willis-Lissie, TX	Pliocene to Pleistocene	Rio Grande Embayment	45 200	10	33	7 700	20 400	50 000	25 400
		Houston Embayment	52 250	0	4	100	2 000	6 200	2 700
Totals – Texas Coastal Plain (recoverable tU)			229 510	64	111				85 000

Notes: The permissive tract area in square kilometres (km²) includes the favourable and prospective areas. Identified and undiscovered uranium resources are estimated as in-place for the Southern High Plains and produced in the Texas Coastal Plain. See: Singer, D.A. and W.D. Menzie (2010), Quantitative mineral resource assessments – an integrated approach. New York, Oxford University Press, for an explanation of quantitative mineral assessment methods. Numbers are converted from pounds U_3O_8 and are rounded to the nearest 100 metric tonnes of uranium (tU). This table and related narrative text in Red Book 2020 had a number of conversion and rounding errors, which have been fixed for this edition of the Red Book.

N_{known} = number of known deposits in the tract that have identified resources (Singer and Menzie, 2010).

N_{und} = number of undiscovered deposits calculated using a regression equation (Singer and Menzie, 2010).

Uranium production

Historical review

Following the passage of the Atomic Energy Act of 1946 (AEA), designed to meet the US government's uranium procurement needs, the Atomic Energy Commission (AEC), from 1947 through 1970, fostered the development of a domestic uranium industry (chiefly in the western United States) through incentive programmes for exploration, development and production. To ensure the supply of uranium ore would be sufficient to meet future needs, the AEC, in April 1948, announced a domestic ore procurement programme designed to stimulate prospecting and build a domestic uranium mining industry. The AEC also negotiated concentrate procurement contracts, under the AEA, as amended in 1954, with guaranteed prices for source materials delivered within specified times. Contracts were structured to allow milling companies that built and operated mills the opportunity to amortise plant costs during the procurement-contract period. By 1961, 27 mills were operating. Overall, 32 conventional mills and several pilot plants, concentrators, upgraders, heap leach, and solution-mining facilities were operating at various times. The AEC, as the sole government purchasing agent, provided the only US market for uranium. Although many of the mills closed soon after completing deliveries scheduled under AEC purchase contracts, several mills continued to produce concentrate for the commercial market after fulfilling their AEC commitments.

The AEA, as amended, legalised the private ownership of nuclear reactors for commercial electricity generation. By late 1957, domestic ore reserves and milling capacity were sufficient to meet government needs. In 1958, the AEC's procurement programmes were reduced in scope and, in order to foster atomic energy use for peaceful purposes, domestic producers of ore and concentrate were allowed to sell uranium to private domestic and foreign buyers. The first US commercial-market contract was finalised in 1966. The AEC announced in 1962 a stretch out of its procurement programme that committed the government to take only set annual quantities of uranium from 1967 through 1970. This programme change also helped sustain a viable domestic uranium industry. The US government's natural uranium procurement programme ended in 1970, and the industry became a private sector, commercial enterprise with no government purchases. The government, however, continues to monitor private industry exploration and development activities to the extent of meeting federal information and data needs.

Exploration by the US uranium industry increased through the 1970s in response to rising prices and the projected large demand for uranium to fuel an increasing number of commercial nuclear power plants that were under construction or planned. US production peaked in 1980 (16 809 tU) and generally declined until 2003. Beginning in 2004, production began increasing again in response to rising uranium prices. Production began decreasing in 2013 in response to an oversupply of uranium on the world market and the resulting lower uranium prices. The oversupply resulted from the reactor shutdowns in Germany and Japan following the accident at the Fukushima Daiichi nuclear power plant. Since 1991, production from ISR mining has accounted for the largest share of US annual uranium production.

Status of production facilities, production capability, recent and ongoing activities and other issues

US uranium mines produced 67 tU in 2019, 76% less than in 2018. Data for 2020 production was withheld. Production in 2019 came from seven facilities: six ISR plants in Nebraska and Wyoming (Crow Butte Operation, Lost Creek Project, Ross CPP, North Butte, Nichols Ranch and Smith Ranch-Highland Operation) and one underground mine. When mined, uranium ore from underground mines is stockpiled and eventually shipped to the White Mesa Mill for milling into U_3O_8 concentrate (yellowcake).

At the end of 2020, one uranium mill (White Mesa in Utah) was operating with a capacity of 1 814 metric tonnes of ore per day. During 2019, the White Mesa Mill did not produce any uranium. In 2020, White Mesa produced about 70 tU from reprocessed on-site pond water and alternative feed material. Vanadium was also recovered from pond returns. Alternative feed material includes uranium extracted during municipal water treatment, process residues from uranium conversion, uranium-bearing tails from other metal recovery operations, and others. Two mills (Shootaring Canyon in Utah and Sweetwater in Wyoming), with a combined capacity of 3 402 metric tonnes of ore per day, were on standby status. Both the Sweetwater and Shootaring Canyon mills have been on standby status since the early 1980s and will require rehabilitation to operate again. Centres that produced uranium in 2019 and 2020 are listed in the table below.

Uranium production centre technical details

(Centres that produced uranium between 1 January 2019 and 31 December 2020)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5	Centre #6
Name of production centre	Crow Butte	White Mesa Mill	Lost Creek	Smith Ranch-Highland and North Butte-Brown Ranch	Ross	Nichols Ranch
Production centre classification[1]	Existing	Existing	Existing	Existing	Existing	Existing
Date of first production	1991	1980	2013	1988	2015	2014
Source of ore						
Deposit name	Crow Butte	Alternative feed material and pond returns	Lost Creek	Smith Ranch, Highland, North Butte and Brown Ranch	Ross (Lance Projects)	Nichols Ranch, Jane Dough and Hank
Deposit type	Sandstone	Sandstone, breccia pipe	Sandstone	Sandstone	Sandstone	Sandstone
Recoverable resources (tU)	W	W	NA	W	W	NA
Grade (% U)	W	W	NA	W	W	NA
Mining operation						
Type (OP/UG/ISR)	ISR	UG and Other	ISR	ISR	ISR	ISR
Size (metric tonnes of ore/day)	NA	NA	NA	NA	NA	NA
Average mining recovery (%)	NA	NA	NA	NA	NA	NA
Processing plant						
Acid/alkaline	Alkaline	Acid	Alkaline	Alkaline	Alkaline	Alkaline
Type (IX/SX)	IX	SX	IX	IX	IX	IX
Size (metric tonnes of ore/day)		1 538				
Average process recovery (%)	NA	NA	NA	NA	NA	NA
Nominal production capacity (tU/year)[1]	385	NA	769	2 116	144	769
Plans for expansion	Deferred	Unknown	Unknown	Deferred	Planned stage expansion, depending on market conditions	Unknown
Other remarks[2]	Operating: Q2 2016 – Production curtailed and wellfield development deferred	Operating	Operating	Operating: Q2 2016 – Production curtailed and wellfield development deferred	Operating	Operating (Placed on standby status Q1 2020)
State	Nebraska	Utah	Wyoming	Wyoming	Wyoming	Wyoming

1. Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Tables 4 and 5.

NA = not available. W = data withheld to avoid disclosure of individual company data. tU= metric tonnes of uranium.

Ownership structure of the uranium industry

Ownership of uranium facilities that produced uranium in 2019 and 2020 are public and privately held firms with both foreign and domestic participation.

Employment in the uranium industry

Employment in the raw materials sector (exploration, mining, milling, and processing) of the US uranium industry generally declined from 1998 to 2003, and then it steadily increased from 2004 to 2008. Employment levels in the uranium industry in 2009 showed the first significant decrease over the preceding five years, but from 2009 through 2012, total uranium employment made marginal gains. Since 2012, however, uranium employment has declined with the decrease in production. In 2020, total employment in the US uranium production industry was 225 person-years (including reclamation employment), a decrease of 15% from the 2019 total of 270 person-years and the lowest on record. The EIA had to withhold individual employment category data in 2020 to protect the anonymity of participants in national-level surveys. In 2020, employment in the uranium production industry spanned at least five states: Colorado, Nebraska, New Mexico, Texas and Wyoming.

Future production centres

Several future production centres are currently in either the permitting or licensing process or under development. Significant activities affecting these production centres are described in the previous sections on conventional and ISR mine development.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

MOX fuel production and use are zero.

Production and/or use of re-enriched tails

The DOE and the Bonneville Power Administration initiated a pilot project to re-enrich a portion of the DOE's tails inventory. This project produced approximately 1 940 metric tonnes of low-enriched uranium between 2005 and 2006 for use by Energy Northwest's 1 190-megawatt electric (MWe) Columbia Generating Station between 2007 and 2015. In mid-2012, Energy Northwest and the United States Enrichment Corp. (USEC), with the DOE, developed a new plan to re-enrich a portion of the DOE's high-assay tails. The 2013 project produced approximately 3 738 metric tonnes of natural uranium, which will be used through 2029 to fuel Energy Northwest and Tennessee Valley Authority (TVA) reactors.

In 2016, the DOE agreed to sell depleted uranium to GE-Hitachi Global Laser Enrichment, LLC (GLE) over a 40-year period, for enrichment at a proposed GLE facility. GLE will finance, construct, own and operate the Paducah Laser Enrichment Facility (PLEF) adjacent to the DOE site. Silex Systems Ltd, an Australian-owned company developing the laser enrichment technology, has licensed GLE to supply the depleted uranium.

In February 2019, Silex Systems Ltd and Cameco Corp. agreed to restructure ownership of GLE with a joint purchase of GE-Hitachi Nuclear Energy's (GEH) share of GLE. Silex holds the majority at 51%, and Cameco increased its share to 49%.

Production and/or use of reprocessed uranium

Reprocessed uranium use and production are zero.

Environmental activities and socio-cultural issues

Remediation activities

Navajo Nation

In 2019, a multiagency group developed a 10-year plan to remediate legacy environmental impacts of uranium mining that took place on the Navajo Nation between 1944 and 1986. The 2020-2029 plan continues the efforts of two previous 5-year plans developed by the US federal government. The 10-year plan developed goals to assess and remediate contaminated structures, assess potential mining impacts on water, develop additional sources of safe drinking water, implement final clean-up and closure of the Tuba City dumpsite, enhance communication and community involvement, develop and support a Navajo workforce and support screening of a uranium-exposed community.

Piketon

Decommissioning and environmental remediation continues at the Portsmouth Gaseous Diffusion Plant in Piketon, Ohio, which closed in 2001. In 2015, the DOE created a comprehensive plan to demolish the process buildings and support structures at the Portsmouth Gaseous Diffusion Plant. The DOE contractor Fluor-BWXT is demolishing three large buildings. Clean-up activities will likely be completed in 2024.

Defense-Related Uranium Mines (DRUM) Program

Federal land management agencies, state abandoned mine land programmes, and tribal governments created the DOE Office of Legacy Management's Defense-Related Uranium Mines (DRUM) Programme to locate and evaluate hazards of the mines that supplied uranium to the US Atomic Energy Commission for defence-related activities. Field crews are validating the locations of these mines and scanning them for health hazards to human populations and wildlife. The programme is divided into three campaigns:

- Campaign 1 (in progress) focuses on evaluating the approximately 2 500 mines on public land and is scheduled to be completed in 2022.
- Campaign 2 is an evaluation of mines on tribal lands and is scheduled for 2023-30.
- Campaign 3 focuses on mines on private land and is scheduled for 2024-30.

Information on the hazards identified by the DRUM programme is shared with partner agencies who can work to safeguard physical hazardous mine features such as open mine entries, areas of subsidence or unstable highwalls.

Legislation/policy

Federal

In 2012, over one million acres of federal land near the Grand Canyon in Arizona were withdrawn from mineral entry for 20 years due to concerns about the environmental impacts of mining in this scenic area of the Colorado Plateau. Studies of potential environmental impacts of mining continue in this area.

In 2018, the US Department of the Interior officially listed uranium as a critical mineral based on Executive Order 13817 issued by President Trump. The US Geological Survey initiated the Earth Mapping Resources Initiative (Earth MRI) to identify focus areas for critical minerals and to fund mapping and geophysical and geochemical surveys to help identify deposits. In 2020, as part of Earth MRI, the US Geological Survey identified over 60 high-priority uranium focus areas that could contain undiscovered uranium resources. State geological surveys evaluated these sites and applied for funding to initiate studies of the mineral potential of some of these focus areas. The US government will award funding for the proposed studies annually based on a competitive evaluation of the focus area's importance for all critical mineral commodities.

Litigation

In June 2019, the US Supreme Court upheld the Commonwealth of Virginia's moratorium on banning uranium mining. This decision upheld earlier rulings by lower US courts that the Commonwealth of Virginia had the right to regulate uranium mining. Coming from the highest US court, this decision effectively prevents the uranium deposit near Coles Hill, Virginia, from development for the foreseeable future.

Regulatory regime

Regulation

The US Nuclear Regulatory Commission (NRC), the US Environmental Protection Agency (EPA), and individual states regulate uranium recovery, but mining regulations for federal lands are administered through the federal agency that controls the land (such as the Bureau of Land Management). Before mining begins, Environmental Impact Statements must be completed, adequate bonding must be posted, and additional regulatory requirements specified by federal and state agencies must be satisfied.

As of December 2020, the NRC was reviewing uranium recovery licence applications for two ISR facilities (one renewal and one expansion) and the agreement states were reviewing three ISR applications (two expansions and one renewal).

US NRC uranium recovery licence applications

Facility	Facility type	Applicant
Crownpoint	ISR – Renewal (NRC)	Hydro Resources, Inc.
North Trend	ISR – Expansion (NRC)	Crow Butte Resources
LC East/KM Horizon	ISR – Expansion	Lost Creek ISR LLC
Kendrick	ISR – Expansion	Stata Energy, Inc.
Smith Ranch-Highland	ISR – Renewal	Power Resources, Inc.

Uranium requirements

Annual US uranium requirements for 2020 to 2040 are projected to decrease from 17 641 tU in 2020 to 16 276 tU in 2040 (EIA high-case estimate). The EIA based this decrease on the possibility that some nuclear power plants may retire early due to financial uncertainties in competitive electricity markets. These estimates include the operations of the new Watts Bar Unit 2 in Tennessee and the construction of Vogtle Unit 3 and Unit 4, scheduled to come online in 2022.

In late July 2019, Ohio became the fifth US state to enact policies that provide compensation or other assistance for nuclear power plants. Connecticut, Illinois, New Jersey and New York have implemented similar support programmes since 2017. These price and market support legislations currently affect 14 of the 96 operating commercial power reactors. Many of the plants in these states had announced plans to permanently shut down due to unfavourable market conditions. Other US states with nuclear power reactors operating in merchant markets are also examining legislative options for their nuclear power industry.

Supply and procurement strategy

In the United States, market forces drive supply and procurement of uranium, and buying and selling are conducted solely in the private sector by firms in the uranium mining and nuclear power industries. Companies can petition the US government to conduct an investigation under Section 232 of the Trade Expansion Act of 1962, as amended, to determine the effect of imports on national security. In 2018, two US domestic mining and milling companies petitioned the US Department of Commerce to investigate whether uranium imports from foreign state-owned enterprises posed a threat to national security. In July 2019, President Trump declined to impose quotas or other trade measures but did establish a Nuclear Fuel Working Group to examine the current state of domestic nuclear fuel production to reinvigorate the entire nuclear fuel supply chain. On 23 April 2020, the DOE released the Administration's Nuclear Fuel Working Group strategy, which contains recommendations to revitalise and strengthen the front end of the nuclear fuel cycle and the domestic nuclear industry. One of the recommendations of the Nuclear Fuel Working Group was to create a national strategic uranium reserve from domestically produced uranium over a 10-year period. In December 2020, a US federal budget was enacted that included the first year of funding for developing this uranium reserve. The DOE will administer the 150 million USD/year plan, which will buy uranium directly from domestic mines and support domestic conversion operations.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Currently, some of the technologies used in the uranium enrichment process in the United States come from foreign sources. These foreign enrichment technologies do not meet national security requirements for enriched uranium. However, it will take time to develop and thoroughly analyse enrichment technologies to inform an acquisition decision for producing unobligated low-enriched uranium (LEU). To that end, the US National Nuclear Security Administration's (NNSA) Domestic Uranium Enrichment strategy includes the NNSA Defense Program's plan to down-blend approximately 20 metric tonnes of highly enriched uranium (HEU) to LEU for use as fuel in tritium production reactors. The uranium will be transferred to the NNSA federal partner, the Tennessee Valley Authority (TVA), only for use as fuel in a reactor producing tritium and not for resale or retransfer. The use of this material complies with long-standing US policy and international commitments that require LEU used for defence purposes to be free of peaceful use restrictions (that is, unobligated). TVA is responsible for preserving the unobligated LEU to be used as fuel in tritium production reactors.

The DOE conducts uranium transfers in accordance with its authority under the Atomic Energy Act of 1954 and consistent with other applicable laws. On 21 August 2018, the Secretary of Energy issued a determination covering the transfer of low-enriched uranium in support of the tritium production mission. The Secretarial Determination establishes the national security purpose of these transfers; therefore, the DOE will conduct these uranium transfers under Section 3112(e)(2) of the USEC Privatisation Act of 1996, which provides for transfers of enriched uranium to any person for national security purposes, as determined by the Secretary of Energy.

Uranium stocks

As of 2020, total commercial inventories (producer and utility stocks) were 47 365 tU, a 6% decrease from the 50 255 tU of inventories held in 2019. Owners and operators of commercial reactors held 87% of commercial inventories, or 41 214 tU. This holding was a 5% decrease from the 43 518 tU owned by this group at the end of 2019.

Enriched uranium inventories held by utilities (including fuel elements in storage) decreased 2% from 2019 to 2020 (from 18 623 tU in 2019 to 18 252 tU in 2020), whereas natural uranium inventories held by utilities (including uranium hexafluoride [UF_6] in storage) decreased 8% from 2019 to 2020 (from 24 894 tU in 2019 to 22 962 tU in 2020).

Uranium prices

Owners and operators of US civilian nuclear power reactors (civilian owners and operators, or COOs) purchased 18 808 tU of deliveries from US suppliers and foreign suppliers during 2020, at a Voglte Unit 3 weighted-average price of USD 86.50/kgU.

The 2020 total of 18 808 tU increased 1% compared with the 2019 total of 18 577 tU. The 2020 weighted-average price of USD 86.50/kgU was 6% less than the 2019 weighted-average price of USD 92.53/kgU and the lowest price since 2007.

Most uranium delivered in 2020 was of foreign origin. Canada was the top source at 22.4% of total deliveries, edging out Kazakhstan, which had 22.1% of total deliveries. Uranium originating in Kazakhstan, Russia, and Uzbekistan accounted for 47% of total uranium purchased by US COOs in 2020. Uranium originating in Canada and Australia together accounted for 34%.

COOs purchased three material types of uranium for 2020 deliveries from 35 sellers. Uranium concentrate accounted for 46% of the 18 808 tU delivered in 2020. Enriched UF_6 accounted for 32%, and natural UF_6 accounted for 22%. During 2020, 24% of the uranium delivered was purchased under spot contracts at a weighted-average price of USD 74.62/kgU. The remaining 76% was purchased under long-term contracts at a weighted-average price of USD 90.32/kgU. Spot contracts are contracts that typically have a one-time uranium delivery for the entire contract, and the delivery typically occurs within one year of contract execution (signed date). Long-term contracts are contracts with one or more uranium deliveries to occur at least a year following the contract execution and, as such, may reflect some agreements in the short and medium terms as well as in the long term.

In 2020, COOs signed 39 new purchase contracts with deliveries in 2020 of 4 596 tU at a weighted-average price of USD 65.55/kgU. Four of these contracts were long-term and received deliveries of 1 234 tU at a weighted-average price of USD 40.09/kgU. The other 35 contracts were spot contracts with 3 363 tU delivered at a weighted-average price of USD 74.88/kgU. COOs report minimum and maximum quantities of future deliveries under contract to allow the option of either decreasing or increasing quantities. At the end of 2020, the maximum uranium deliveries for 2021 through 2030 under existing purchase contracts for COOs totalled 74 615 tU. Also at the end of 2020, unfilled uranium market requirements for 2021 through 2030 totalled 72 308 tU. These contracted deliveries and unfilled market requirements combined represent the maximum anticipated market requirements of 146 923 tU over the next 10 years for COOs.

Average US uranium prices, 2006-2020

(USD per kilogram U-equivalent)

Year	Spot contracts	Long-term contracts
2020	74.6	90.3
2019	72.5	98.1
2018	71.52	106.56
2017	58.13	108.10
2016	76.82	119.59
2015	95.45	119.41
2014	95.26	129.29
2013	113.95	140.39
2012	132.69	144.68
2011	142.18	145.33
2010	114.36	131.11
2009	120.76	118.91
2008	174.06	108.12
2007	229.44	63.57
2006	102.64	42.59

Source: US Energy Information Administration, *Uranium Marketing Annual Report*, 2020, Table 7.

Uranium exploration and development expenditures and drilling effort – domestic

(in USD million)

	2017	2018	2019	2020
Industry* exploration expenditures[1]	3.7	W	W	W
Government exploration expenditures	0	0	0	NA
Industry* development expenditures[2]	40.6	W	W	W
Government development expenditures	0	0	0	NA
Total expenditures	44.3	W	W	W
Industry* exploration drilling (m)[3]	W	W	W	W
Industry* exploration holes drilled[4]	W	W	W	W
Industry exploration trenches (metres)	NA	NA	NA	NA
Industry exploration trenches (number)	NA	NA	NA	NA
Government exploration drilling (m)	0	0	0	NA
Government exploration holes drilled	0	0	0	NA
Government exploration trenches (m)	NA	NA	NA	NA
Government exploration trenches (no.)	NA	NA	NA	NA
Industry* development drilling (m)[5]	W	W	W	NA
Industry* development holes drilled[6]	W	W	W	NA
Government development drilling (m)	0	0	0	NA
Government development holes drilled	0	0	0	NA
Subtotal exploration drilling (m)	W	W	W	NA
Subtotal exploration holes	W	W	W	NA
Subtotal development drilling (m)	W	W	W	NA
Subtotal development holes	W	W	W	NA
Total drilling (m)[7]	59 741	W	W	W
Total number of holes drilled[8]	420	W	W	W

1. Source: US Energy Information Administration, *Domestic Uranium Production* Report, 2020, Table 8, Exploration.

2. Source: US Energy Information Administration, *Domestic Uranium Production* Report, 2020, Table 8, Drilling + Land + Reclamation.

3. Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 1, Exploration, feet (converted to metres using EIA *Uranium Industry Annual* Appendix D Uranium Conversion Guide).

4. Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 1, Exploration, Number of Holes.

5. Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 1, Development Drilling.

6. Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 1, Development Drilling.

7. Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 1.

8. Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 1.

* = Non-government. NA = Not available.

W = Data withheld to avoid disclosure of individual company data.

m = Metres.

no. = Number.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	W	18 000	W	NA
Open-pit mining (OP)	0	W	See Note 1	W	NA
In situ leaching alkaline	0	W	61 231	W	NA
Unspecified	0	0	0	0	NA
Total	0	12 000	79 231	149 538	NA

Source: US Energy Information Administration, *Domestic Uranium Production Report, 2019*, Table 10; 2020 data withheld.

Note 1: US reserves data do not draw a distinction between UG and OP; the combined value is assigned to UG.

kgU = Kilogram of uranium. W = Data withheld to avoid disclosure of individual company data. NA = Not available.

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	NA	NA	NA	NA
Conventional from OP	0	NA	NA	NA	NA
In situ leaching acid	0	NA	NA	NA	NA
In situ leaching alkaline	0	NA	NA	NA	NA
In-place leaching*	0	NA	NA	NA	NA
Heap leaching** from UG	0	NA	NA	NA	NA
Heap leaching** from OP	0	NA	NA	NA	NA
Unspecified	0	NA	NA	NA	NA
Total	0	12 000	79 231	149 538	NA

Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2019, Table 10; 2020 data withheld.

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining because the category is used in conjunction with both.

NA = Not available. kgU = Kilogram of uranium. UG = Underground mining. OP = Open-pit mining.

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unconformity-related	0	0	0	0	NA
Sandstone	0	12 000	79 231	149 538	NA
Intrusive	0	0	W	W	NA
Volcanic and caldera-related	0	0	W	W	NA
Other*	0	0	W	W	NA
Total	0	12 000	79 231	149 538	NA

Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2019, Table 10; 2020 data withheld.

* Includes surficial, collapse breccia pipe, phosphorite and other types of deposits, as well as rocks with elevated uranium content. Pegmatite, granites and black shale are not included.

NA = Not available. kgU = Kilogram of uranium.

Historical uranium production by production method

(tonnes U in concentrate)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining*	0	0	0	0	0
Underground mining*	NA	W	W	W	NA
In situ leaching	NA	W	W	W	NA
Co-product/by-product	NA	W	W	W	NA
Total**	376 923	67	W	376 990	NA

Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 2; 2020 data withheld.

Note: Data not available prior to 1968. W = Data withheld to avoid disclosure of individual company data. NA = Not available.

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

** Also includes, in various years, mine water, mill site clean-up and mill tailings, and well field restoration as sources of uranium.

Historical uranium production by processing method[a]

(tonnes U in concentrate)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	NA	W	W	W	NA
In-place leaching*	NA	W	W	W	NA
In situ leaching	NA	W	W	W	NA
Other methods**	NA	W	W	W	NA
Total	376 923	67	W	376 990	NA

Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 3; 2020 data withheld.

Note: Data are available from 1947 to present. W = Data withheld to avoid disclosure of individual company data. NA = Not available.

[a] May not equal production by method as it is produced concentrates and may include ore mined and shipped to a mill during the same year, ore that was mined during a previous year and later shipped from mine-site stockpiles, or ore obtained from drawdowns of stockpiles maintained at a mill site. Uranium production by processing method may additionally include uranium from mill clean-up, mine water, tailings water and other materials in various years.

* Also known as stope leaching or block leaching.

** Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2017	2018	2019	2020	Total through end of 2020	2021 (expected)
Unconformity-related	NA	NA	NA	NA	NA	NA
Sandstone	NA	NA	NA	NA	NA	NA
Hematite breccia complex	NA	NA	NA	NA	NA	NA
Quartz-pebble conglomerate	NA	NA	NA	NA	NA	NA
Vein	NA	NA	NA	NA	NA	NA
Intrusive	NA	NA	NA	NA	NA	NA
Volcanic and caldera-related	NA	NA	NA	NA	NA	NA
Metasomatite	NA	NA	NA	NA	NA	NA
Other*	NA	NA	NA	NA	NA	NA
Total	NA	NA	NA	NA	NA	NA

* Includes surficial, collapse breccia pipe, phosphorite and other types of deposits, as well as rocks with elevated uranium content. Pegmatite, granites and black shale are not included.

NA = Not available.

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
0	0	W	W	0	0	W	W	W	W

Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 2.

W = Data withheld to avoid disclosure of individual company data. tU = Metric tonnes of uranium.

Uranium industry employment at existing production centres

(person-years)

	2018	2019	2020	2021 (expected)
Total employment related to existing production centres[1]	234	155	W	NA
Employment directly related to uranium production[2]	207	115	W	NA

1. Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 6, all sectors except Reclamation

2. Source: US Energy Information Administration, *Domestic Uranium Production Report*, 2020, Table 6, all sectors except Exploration and Reclamation.

NA = Not available.

Short-term production capability

(tonnes U/year)

2020				2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA

NA = Not available.

Re-enriched tails production and use[1]

(tonnes of natural U-equivalent)

Re-enriched tails	Total through end of 2017	2018	2019	2020	Total through end of 2020	2021 (expected)
Production	5 677.8	0	0	0	5 677.8	0
Use	1 939.8	0	0	0	1 939.8	0

1. Data provided by Energy Northwest, owner-operator of the Columbia Generating Station.

Net nuclear electricity generation[1]

(TWh net)

	2019	2020
Nuclear electricity generated	809	789.9

1. OECD-NEA Nuclear Energy Data 2021.

Installed nuclear generating capacity to 2040[1]

(GWe net)

2019	2020	2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High
98.12	96.62	91.9	91.9	61.8	86.2	55.6	86.8	51.9	87.0

1. OECD-NEA Nuclear Energy Data 2021.

Annual reactor-related uranium requirements to 2040 (excluding MOX)[1]

(metric tonnes U)

2019	2020	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
17 684	16 886	10 738	14 630	10 738	14 630	10 040	15 755	8 025	17 589	7 499	16 727

1. OECD_NEA Nuclear Energy Data 2021.

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks	Enriched uranium stocks	Depleted uranium stocks	LWR reprocessed uranium stocks	Total
Government[1]	5 285	4 396	90 000	NA	99 681
Producer[2]	NA	NA	NA	NA	7 645
Utility[2]	24 072[3]	18 860[4]	NA	NA	42 933
Total	NA	NA	NA	NA	150 259

1. US government analysis of the *Potential Impacts of Uranium Transfers on the Domestic Uranium Mining, Conversion, and Enrichment Industries*, 2017.

2. US Energy Information Administration, *Uranium Marketing Annual Report*, 2018, Tables 22 and 23.

3. The value for natural uranium stocks in this table does not include natural uranium hexafluoride (UF6). Values for total utility natural uranium stocks in the text include natural UF_6.

4. The value for enriched uranium stocks in this table does not include fabricated fuel elements held in storage prior to loading in the reactor. Values for total utility enriched uranium in the text include fabricated fuel elements in storage.

NA = Not available.

Uzbekistan*

Uranium exploration and mine development

Historical review

Uranium exploration in Uzbekistan predates the 1945 start-up of uranium mining at the small vein ore deposits (Shakaptar, Uiguz Sai and others) in the Fergana Valley of Eastern Uzbekistan. Exploration conducted during the early 1950s, including airborne geophysical surveys, ground radiometry and underground work over the remote Kyzylkum desert in central Uzbekistan, led to the discovery of the Uchkuduk and Ketmenchi uranium deposits in 1952, the Bukinai deposit in 1959, the Sabyrsai deposit in 1960, and the South Bukinai, Sugraly and Lyavlyakan deposits in 1961. All deposits were discovered by the Krasnokholmskaya exploration company, which was renamed Kyzyltepageologia in 1990. Drilling confirmed the initial discovery and development of the first mine at the Uchkuduk deposit in 1959, followed by development of the Sabyrsai deposit. Both deposits were initially mined using open-pit and underground mining methods until 1975.

In the early 1960s, development of the in situ leaching (ISL) mining technique for recovery of uranium from sandstone deposits led to the re-evaluation of previously ignored deposits including Lavlakan and Ketmenchi and to an increase in exploration efforts in the sedimentary environments of the Kyzylkum desert. Three uranium districts with 24 sandstone-type deposits amenable to ISL mining have been established since the Uchkuduk discovery in 1952.

Several black shale-type uranium deposits, including Dzhantuar, Rudnoye, Kostcheka, Voskhod and Dzitym, were identified during the 1960s in the Auminzatau Mountains district. Mineralisation is in black shale related to strata-structure-type and occurs in stratiform and stockwork lodes. Resources of individual deposits are relatively small, and grades range from 0.02 to 0.13% U, averaging 0.05% U.

Since 1994, the Navoi Mining and Metallurgy Combinat (NMMC) has funded all uranium exploration activities in Uzbekistan. In 1995-1996, Kyzyltepageologia developed the known resources of the Severny (Northern) Kanimekh, Alendy, Kendykijube and Tokhumbet deposits. In addition, assessments of undiscovered resources were completed in the Kyzylkum, Bukhara-Khiva and Fergana Provinces.

Between 1997 and 2000, Kyzyltepageologia evaluated the known resources of the Kendiktyube, Severny, Kanimeh, Tokhumbet and Ulus deposits, some of which were handed over to the NMMC for further investigation. Delineation drilling was carried out in 2002 on the Kendytyube and Tokhumbet deposits, then transferred to Mining Division No. 5 for commercial development.

From 2003 to 2004, Kyzyltepageologia completed exploration and evaluation works in the Kendyktyube and Tokhumbet deposits, the south-western flanks of the Sugraly deposit, and the western and eastern flanks of the Ketmenchi deposit. Kyzyltepageologiya further explored the northern and southern areas of Central Kyzylkum with government funding.

* Report prepared by the NEA/IAEA, based on previous Red Books, a report submitted by the Navoi Mining and Metallurgy Complex (NMMC), and public data.

In August 2009, GoscomGeology (State Geology and Mineral Resources Committee) and the China Guangdong Nuclear Uranium Corp. (CGN-URC) set up a 50%-50% uranium exploration joint venture, Uz-China Uran, to focus on the black shale deposits in the Boztau area of the Central Kyzylkum Desert in the Navoi region. Approximately 5 500 tU resources have been reported. From 2011 to 2013, CGN-URC was to develop technology for the production of uranium and vanadium from these black shale deposits. No activities have been reported since that time.

In July 2013, the Japan Oil, Gas and Metals National Corporation (JOGMEC) received a five-year licence for uranium exploration at two prospective areas in the country's Navoi region. JOGMEC indicated that they would implement geological exploration work in the Juzkuduk and Tamdiykuduk-Tulyantash prospective ore fields. Historical uranium resources discovered at the licensed sites total about 13 000 tU, according to Uzbek government data.

Due to recent low uranium prices, development of Uzbekistan's black shale deposits was delayed indefinitely.

Recent and ongoing uranium exploration and mine development activities

In December 2019, France and Uzbekistan established the French-Uzbek uranium joint venture, the Nurlikum Mining LLC, which is 51% owned by Orano (formerly Areva) and 49% by Uzbekistan's State Committee on Geological and Mineral Resources (GoscomGeology). Nurlikum Mining will conduct uranium exploration and mining operations throughout Uzbekistan, focusing on sandstone-type uranium mineralisation in the Djengeldi region of Kyzylkum province. Orano will contribute capital and technology to the JV, while the Uzbekistan side will contribute historical exploration results. Nurlikum's first field exploration commenced in 2020 and consisted of 40 drill holes. The planned exploration campaign for 2021 envisioned the drilling of around 300 boreholes.

Uranium resources

Uzbekistan's uranium resources occur primarily in sandstone-type and black shale-type deposits.

All significant sandstone roll-front type uranium resources are found in the Central Kyzylkum area, comprising a 125 km-wide belt extending over a distance of about 400 km from Uchkuduk in the northwest, to Nurabad in the southeast. Only sandstone-type deposits have been exploited.

In 2014, GoscomGeology reported in situ uranium resources in Uzbekistan amounting to 185 800 tU, with 138 800 tU of sandstone type and 47 000 tU of black shale-type.

As of 1 January 2021, Uzbekistan's total identified recoverable uranium resources at a cost <USD 130/kgU amounted to about 131 290 tU (170 285 tU of in situ resources). Compared with the data as of 1 January 2019, this is a very slight decrease of 1 010 tU in total recoverable resources. About 98% of reasonably assured resources (RAR) and 30% of inferred sandstone-type resources are controlled by the NMMC, which is owned by the government of Uzbekistan and the balance of which resides in a "fund of undistributed resources". The table below gives a breakdown of resources under the control of the NMMC by status and categories.

Prognosticated resources are estimated at about 25 000 tU.

In situ resources controlled by the NMMC

(tonnes U as of 1 January 2021)

Status	Deposit	Resources category*		
		C_1 + B	C_2	C_1+C_2
Northern Mining Unit				
Sandstone type for ISL mining	Uchkuduk	148	0	148
	Kendyk-Tyube	405	0	405
	Mejlisaj	3 572	28	3 600
Subtotal ISL under development		**4 125**	**28**	**4 153**
Prospective in black shales	Kushkuduk open pit	0	2 839	2 839
	Kushkuduk open-pit waste piles	0	79	79
	Ma"danli (Rudnoe)	2 412	484	2 896
Subtotal prospective in black shales		**2 412**	**3 402**	**5 814**
Total Northern Mining Unit		**6 537**	**3 430**	**9 967**
Mining Unit No 5				
Sandstone type for ISL mining	Shimolij Bukinoj	3 586	1 208	4 793
	Istiklol	2 748	109	2 857
	Kukhnur	2 086	0	2 086
	Aulbek	3 067	0	3 067
	Zhanubij Bukinoj	149	0	149
	North Kanimekh	5 521	1 233	6 754
	Beshkak	0	688	688
	Lojliken	2	2 584	2 586
	Aksaj-1	5	0	5
	Terekuduk	607	146	753
	Dzhengeldy	1 316	0	1 316
	Sugrali	2 149	3 346	5 495
	Zhanubij Sugrali	1 945	0	1 945
	Ketmonchi	1 179	101	1 280
	Maibulak	455	0	455
Total Mining Unit No 5		**24 815**	**9 414**	**34 229**
Southern Mining Unit				
Sandstone type for ISL mining	Shark	472	0	472
	Ulus	192	0	192
	Nurbulok	536	0	536
	Ingichki	657	33	690
Total Southern Mining Unit		**1 857**	**33**	**1 890**
NMMC total		**33 209**	**12 877**	**46 086**
Including sandstone type for ISL development		30 797	9 476	40 272
Including black shales type for OP mining		2 412	3 402	5 814

* Resource categories according to the national Uzbekistan classification system. B and C1 resources correlate with RAR and C2 with inferred resources (see Appendix 3, Figure A3.1).

Uranium production

Historical review

Uranium production in Uzbekistan began in 1946 at several small volcanic vein deposits in the Fergana valley and Kazamazar uranium district. The two largest deposits, Alatanga and Chauli, contained 4 500 tU each. Underground mining was undertaken from the late 1940s to the early 1960s. Cumulative production is estimated in the order of several thousand tU. The ore was processed in the Leninabad uranium production centre in Tajikistan.

The mining operator for the sandstone-type Uchkuduk and Sabyrsai deposits was Mining Complex No. 2, which was established in September 1958. In 1967, it was renamed the Navoi Mining and Metallurgy Combinat (NMMC). The NMMC is part of the Uzbekistan state holding company Kyzylkumredmetzoloto, which undertakes all uranium mining in the country.

In the late 1950s, the NMMC commenced operation focusing on uranium and gold production in the desert region of Central Kyzylkum province. Early uranium mining was by underground (to 1990) and open pit (to 1994).

The first ISL tests occurred at the Uchkuduk deposit in 1963, followed by ISL tests at the Sabyrsai, South Bukinai and Ketmenchi deposits in 1968. Commercial ISL mining in Uzbekistan began in 1975. In 1980, ISL accounted for 29% of total uranium production and by 1985 ISL comprised 56% of total production. Since 1995, the NMMC has been producing uranium using only ISL technology. Annual production peaked in the 1980s, when 3 700 to 3 800 tU were recovered.

In 2008, the NMMC started mining the major new Northern Kanimekh deposit, northwest of Navoi. Northern Kanimekh ore occurs 260-600 m below the surface, with 77% of the uranium resources present at 400-500 m depth. The NMMC has also started building a pilot plant for ISL at the Alendy and Yarkuduk deposits, and began operating the Aulbek ISL mine in Central Kyzylkum, as well as developing the Meilysai deposit. The Aulbek mine at the deposit of the same name commenced production in 2013.

The NMMC has developed and implemented two new technologies of acid ISL for ores with high carbonate content. The first is a bicarbonate-acid method that is used for ores with a carbonate content above 2%. It is based on bicarbonate ion generation during the soft acidification stage, which oxidises and dissolves uranium minerals. This method reduces the kinetics of the leaching process, but chemical plugging may occur at the final leaching stage. The repair and restoration procedures for wells is reduced by 2.5-3 times using this method.

The second method uses a mini-reagent technology that is applied for ores with a carbonate content >0.5% located in an artesian aquifer. At the first stage, a preliminary ore oxidation occurs by pumping compressed air into the aquifer. At the second stage, slightly acidic solutions, formed during aquifer saturation with atmospheric oxygen, dissolve the contained uranium.

The implementation of these two technologies has significantly reduced acid consumption and in turn operating costs by 20-30%. Another important advantage has been the low impact of ISL mining on the total mineralisation and chemical composition of productive aquifers during and after the leaching process.

Status of production capability and recent and ongoing activities

The NMMC is among the top 10 global gold and uranium mining companies and is the biggest mining company in Uzbekistan.

The NMMC produces uranium by ISL at three mining divisions that operate nine uranium deposits at depths between 120 to 500 metres:

- the Northern Mining Unit in Uchkuduk operates the Kendyktube deposit;
- the Southern Mining Unit in Nurabad operates the Sabyrsai deposit;

- Mining Unit No. 5 in Zafarabad is the largest division of the three operators of the Northern Bukinai, Lyavlyakan, Beshkak, Ketmenchi, Sugraly, Tokhumbet and Kanimekh deposits.

All mining units produce "yellow cake" uranium concentrates on-site and send it by rail to the Hydrometallurgical Plant No. 1, located in Navoi, for further processing and purification. The NMMC exports all produced uranium. Annual production amounted to approximately 3 300 tU to 3 500 tU from 2015 to 2020.

The NMMC promotes monitoring of working conditions and environmental protection. Local and central divisions of the national health monitoring authority, the National Committee for Nature Protection and the National Mining Monitoring Authority conduct radiation monitoring of all NMMC activities. Monitoring data from peripheral observation wells shows that for productive aquifers at all ISL sites, the natural geochemical background of the formation water is unchanged at a distance of 200-300 m from the ore body boundary, regardless of the leaching technology used (sulphuric acid, bicarbonate-acid or mini-reagent). Radiation monitoring at work locations, supervised areas and the environment shows that the average annual effective equivalent radiation dose does not exceed permitted levels. For example, for a critical group of the population, radiation does not exceed one millisievert per year, which corresponds to the basic limit adopted by the International Commission on Radiological Protection (ICRP).

Ownership structure of the uranium industry

All uranium produced by the NMMC is owned by the government of Uzbekistan.

In 2019, Uzbekistan began a major reorganisation of the NMMC, separating the uranium mining division from gold enterprises. In March 2020, a presidential decree outlined official plans to create State Enterprise Navoiuran, which will focus on uranium and rare earth metals, while the NMMC will focus on gold and state company Fund NMMC will manage non-core assets. It is expected that the uranium business transformation to Navoiuran will be completed in 2023.

Employment in the uranium industry

Five towns support uranium and gold production activities: Uchkuduk, Zarafshan, Zafarabad, Nurabad and Navoi, with a combined population of about 500 000. These towns remain central to the five mining districts. Uranium industry employment in 2020 was about 7 500, though approximately 59 000 were employed by the NMMC overall in 2015, with gold mining and other activities included (Navoi Mining and Metallurgy Combinat, 2015).

Uranium policies, uranium stocks and uranium prices

Until 1992, all uranium produced in Uzbekistan was shipped to Russia. From 1992 through 2013, practically all of Uzbekistan's uranium production was exported to the United States and other countries through the Nukem company. In 2008, Korea's KEPCO signed agreements to purchase 2 600 tU over six years to 2015, for about USD 400 million. In 2013, 1 663 tU was supplied to China according to the country's custom import statistics. In May 2014, China's CGN agreed to buy USD 800 million of uranium through to 2021. Uzbekistan's state-owned NMMC has also signed a contract to supply 2 000 tU to India from 2014 through 2018.

In December 2019, Uzbekistan agreed to sell uranium to two Japanese trading companies. The NMMC signed separate contracts with ITOCHU (valued at USD 636.4 million) and Marubeni (valued at USD 510.1 million) with both agreements covering uranium deliveries between 2023 and 2030.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
In situ leaching acid	27 240	27 240	47 480	47 480	80
Open pit	0	0	1 690	1 690	70
Total	27 240	27 240	49 170	49 170	

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
In situ leaching acid	27 240	27 240	47 480	47 480	80
Unspecified	0	0	1 690	1 690	70
Total	27 240	27 240	49 170	49 170	

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	27 240	27 240	47 480	47 480	80
Black shales	0	0	1 690	1 690	70
Total	27 240	27 240	49 170	49 170	

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
In situ leaching acid	24 900	24 900	49 220	49 220	80
Open pit	0	0	32 900	32 900	70
Total	24 900	24 900	82 120	82 120	

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
In situ leaching acid	24 900	24 900	49 220	49 220	80
Unspecified	0	0	32 900	32 900	70
Total	24 900	24 900	82 120	82 120	

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	24 900	24 900	49 220	49 220	80
Black shales	0	0	32 900	32 900	70
Total	24 900	24 900	82 120	82 120	

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
24 800	24 800	24 800

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	NA

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Open-pit mining*	36 249	0	0	36 249	0
Underground mining*	19 719	0	0	19 719	0
In situ leaching	84 498	3 500	3 512	91 510	3 520
Total	140 466	3 500	3 512	147 478	3 520

* Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Ownership of uranium production in 2020

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
3 512	100	0	0	0	0	0	0	3 512	100

Uranium industry employment at existing production centres

(Person-years)

	2018	2019	2020	2021 (expected)
Employment directly related to uranium production	7 340	7 387	7 500	7 700

Short-term production capability

(tonnes U/year)

2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
3 000	3 000	3 000	3 000	2 000	2 500	2 000	2 500
2035				**2040**			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
500	2 500	800	2 500	0	2 000	0	2 000

Mid-term production projection

(tonnes U/year)

2021	2022	2025	2030	2035	2040
3 520	3 500	3 000	2 500	2 500	2 000

Viet Nam

Uranium exploration and mine development

Historical review

Uranium mineralisation in Viet Nam is associated with rare earth element deposits (Lao Cai province), phosphate deposits (Cao Bang province), and sandstone and coal deposits (Quang Nam province). The first exploration programmes were initiated before 1955 by French geologists of the Geological Department of Indochina. Beginning in 1978, a systematic regional exploration programme was conducted over the entire country using radiometric methods combined with geological observations. About 25% of the country was also covered by airborne radiometric and magnetic surveys at a scale of 1:25 000 and 1:50 000, respectively. This led to the discovery of several promising areas in the provinces of Cao Bang, Lao Cai, Yen Bai and Quang Nam. Between 1997 and 2002, the Geological Division for Radioactive and Rare Elements (GDRRE) of the Ministry of Natural Resources and Environment carried out detailed uranium exploration and evaluation (including drilling, trenching, and bulk sampling) in the Palau and Parong areas of the Quang Nam province.

Recent and ongoing uranium exploration and mine development activities

Since 2010, the GDRRE has been carrying out uranium exploration in the Parong area in the Quang Nam province of central Viet Nam. The project consists of an investigation and evaluation of Triassic sandstone-type uranium deposits.

Exploration activities on the Parong deposit, covering an area of 1.9 km^2, consist of geophysical and geological surveys, trenching, drilling, and mining tests. Over the main part of the deposit, 712 holes (60 954 m) have been drilled on a 25 x 25 m^2 grid to depths of between 30 and 150 m. Extensions of the deposit have also been drilled on a more widely spaced grid (between 50 x 50 m^2 and 50 x 25 m^2). A mining test was conducted via a 130 m adit from which 3 holes were drilled to 300 m for hydrogeological tests. Results showed a limited amount of water in the formations.

Mineralisation at Parong is associated with medium- to coarse-grained sandstone with organic matter. Three main levels of mineralisation in reduced formations have been defined, separated by oxidised sandstones. Mineralisation over a lateral extension of 200-300 m has been intersected and varies in thickness from a few centimetres to a few metres.

In support of this exploration project, the Institute for Technology of Radioactive and Rare Elements (ITRRE) has carried out research on ore leaching treatment methods, laboratory and pilot-scale tests, as well as investigations on the management of mining wastes and tailings. The results show that the heap leach method is suitable for the low-grade Parong ore, with uranium recovery of over 75%.

Current uranium exploration activities are focused on the recovery of thorium and uranium from rare earth concentrates. Research has been carried out by the ITRRE. A continuous counter-current extraction process for the simultaneous recovery of thorium and uranium from the Yen Phu rare earth concentrate leach solutions was developed. Separation of thorium and uranium from xenotime leach solutions was achieved by solvent extraction using primary and tertiary amines. The results show that the extraction method is suitable for the recovery of thorium and uranium from rare earth concentrate with thorium and uranium purities of greater than 99%. Uranium exploration and research on uranium extraction from uranium ores are continuing.

Uranium resources

Identified conventional resources

In 2011-2012, the uranium potential of part "A" of the Parong area (drilled at a 25 x 25 m^2 grid) was assessed. Uranium resources, estimated using a 0.0085% U cut-off grade, amounted to 1 200 tU at an average grade of 0.034% U. These resources are classified as reasonably assured resources in the highest cost category (<USD 260/kgU or <USD 100/lb U_3O_8).

From 2013 to 2015, the uranium potential of part "G" of the Parong-Palua area was assessed. Inferred uranium resources are estimated at 1 081 tU.

From 2016 to 2019, estimation continued of the uranium potential of remaining parts "B", "C", "D" and "F" of the Palua-Parong.

Results of a previous evaluation of uranium resources as of 31 December 2008 in the main area of the Quang Nam province showed that:

- the Palua deposit consists of five orebodies with total resources amounting to 4 596 tU, including 984 tU inferred resources and 3 612 tU prognosticated;
- the Parong deposit consists of seven orebodies with total resources amounting to 3 867 tU, including 1 200 tU inferred resources and 2 667 tU prognosticated;
- the Khehoa-Khecao deposit consists of four orebodies with total resources amounting to 5 803 tU, including 1 125 tU inferred resources and 4 678 tU prognosticated;
- the Dong Nam Ben Giang deposit consists of eight orebodies with total resources amounting to 1 556 tU, including 337 tU inferred resources and 1 219 tU prognosticated;
- resources of the An Diem deposit amount to 1 853 tU, including 354 tU inferred and 1 499 tU prognosticated.

The deposits of the Quang Nam province described above amount to a total of 4 000 tU inferred resources, 13 675 tU prognosticated resources and 17 675 tU combined inferred and prognosticated resources.

Undiscovered conventional resources (prognosticated and speculative resources)

The results of geological exploration conducted by the GDRRE show that there are more than ten uranium occurrences and deposits located in the northern provinces (Lai Chau, Lao Cai, Yen Bai, Son La, Ha Giang, Cao Bang, PhuTho, and Thai Nguyen), as well as in the highlands and central provinces.

Uranium deposits in the Lai Chau province are associated with rare earth element deposits. In the Cao Bang province, uranium mineralisation is associated with phosphate deposits, and in the Quang Nam province, uranium is associated with sandstones and in coal deposits.

The undiscovered conventional uranium resources as of 31 December 2008 amounted to a total of 81 200 tU prognosticated and 321 600 tU speculative resources. Some of the prognosticated resources include: 3 612 tU at Palua; 2 667 tU at Parong; 4 678 tU at Khehoa-Khecao; 1 219 tU at Dong Nam Ben Giang; and 1 499 tU at An Diem.

Unconventional resources and other materials

Uranium exploration activities associated with rare earth element ores (Dong Pao bastnaesites, Namxe bastnaesite, YenPhu xenotime and beach sand monazite, etc.) are being conducted.

Uranium production

No uranium has been produced in Viet Nam.

Future production centres

The objective of the current uranium exploration programme is to increase the resource base to a total of 5 500 tU_3O_8 (4 665 tU) inferred and 8 000 tU_3O_8 (6 780 tU) prognosticated, as well as to determine the feasibility of mining these deposits. The ITRRE has researched ore processing and has started to survey the environmental conditions of future mining operations. No production centre is planned at this time.

Environmental activities and socio-cultural issues

Environmental activities, such as monitoring the environmental impacts resulting from exploration, are being carried out.

Uranium requirements

Viet Nam had a plan to develop several nuclear power plants with up to 14 nuclear reactors with a total net nuclear electricity generating capacity of about 15 000 MWe to 16 000 MWe by the year 2030. Seven potential build sites had been selected with each site having the potential to accommodate four to six units.

In March 2010, the Prime Minister of Viet Nam approved the plan for the implementation of the NinhThuan Nuclear Power Project, which included the PhuocDinh and Vinh Hai Nuclear Power Plants.

Under this plan, the first nuclear power plant would have consisted of two VVER-type pressurised water reactors (PWRs) with a total net nuclear electricity generating capacity of about 2 000 MWe, built in co-operation with Rosatom. This plant would have been located in the PhuocDinh commune, Thuan Nam district, NinhThuan province. The second nuclear power plant, to have been built in co-operation with Japan Atomic Power Co., would have had the same generating capacity (2 x 1 000 MWe) and been located in the Vinh Hai commune, Ninh Hai district, NinhThuan province. The expected annual reactor-related uranium requirements would have been satisfied by imports and domestic production.

Because of a lack of funding at the end of 2016, the Viet Nam government decided to abandon plans to build the NinhThuan Nuclear Power Plant.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	0	0	0	1 200
Total	0	0	0	1 200

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Heap leaching*	0	0	0	1 200
Total	0	0	0	1 200

* From open-pit and underground mining.

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	0	1 200
Total	0	0	0	1 200

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unspecified	0	0	0	4 000
Total	0	0	0	4 000

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unspecified	0	0	0	4 000
Total	0	0	0	4 000

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	0	4 000
Total	0	0	0	4 000

Prognosticated conventional resources

(in situ tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
NA	NA	81 200

Speculative conventional resources

(in situ tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	321 600

Zambia*

Uranium exploration and mine development

Historical review

Uranium was first identified in Zambia (then Northern Rhodesia) at the site of the Mindola copper mine in Kitwe, leading to the mining of this small deposit between 1957 and 1959. A total of 102 tU_3O_8 (86 tU) was produced. Although no uranium has been produced from that mine or any other in Zambia since then, exploration activity has been carried out periodically by the government and by private companies.

Sporadic uranium exploration activities took place during the 1980-1990s but attention was primarily focused on copper. It was only in the mid-2000s that interest in uranium was stimulated by the dramatic rise in the spot market price for uranium.

The exploration environment in Zambia underwent a fundamental change in 1969. Prior to this date, all mineral rights were held privately, but in 1969 these rights reverted to the state. That same year, the state also effectively nationalised mining by becoming a majority shareholder in all mining companies active in the country (principally copper). Financial realities, including a decline in copper prices, along with recommendations from external bodies, such as the World Bank and International Monetary Fund, encouraged the state to enter into a process of privatisation. This became a reality in 1997 with the primary objective of encouraging foreign investment in the country.

During the 1980s, active exploration for uranium by government and private companies within the Katanga metasediments revealed small, isolated medium-grade deposits in the Dome areas of North-Western Province. The Karoo sediments were also prospected by private companies and revealed some small low-grade deposits at shallow depths. Speculative resources were estimated at 35 000 tU.

Recent and ongoing uranium exploration and mine development activities

In mid-2011, Equinox Minerals was taken over by Barrick Gold Corp. for CAD 7.3 billion. At that time, a total of 4.2 Mt of uraniferous ore at a grade of 0.118% U_3O_8 (0.1% U) was stockpiled at the Lumwana copper mine, which could be processed at a later date if Barrick decided to build a uranium mill for an estimated cost of USD 200 to 230 million. In 2012, drilling programmes at Lumwana were focused on resource definition at Chimiwungo, reserve delineation at Chimiwungo and Malundwe, extension exploration drilling at Chimiwungo and condemnation drilling to test for economic mineralisation in areas of planned mining infrastructure. A total of 237 277 m of diamond drilling and 49 029 m of reverse circulation drilling was completed during 2012 in order to better define the limits of mineralisation and develop an updated, more comprehensive block model of the ore body for mine planning purposes. Total resources, including the uranium ore stockpiled at Malundwe, amounted to 7 492 tU at an average grade of 0.07% U. However, the ore body did not meet economic expectations. The drilling defined significant additional mineralisation, some at higher grades. However, much of this mineralisation was deep and would therefore require a significant amount of waste stripping, making it uneconomic based on the expected operating costs and current market copper prices.

* Report prepared by the NEA/IAEA, based on previous Red Books and company reports.

Activity continued on several key initiatives to lower costs, including improvements to operating systems and processes.

Denison Mines Corp. completed extensive drilling in 2011 and 2012 on their Mutanga Project sandstone-hosted deposits. Airborne geophysical techniques were used to locate anomalies and potential uranium mineralisation. Near-surface mineralisation at the Dibwe East zones 1 and 2 is consistent over a strike length of 4 km, with a core area of high-grade ore. Future exploration activities are expected to include extensive surficial geochemistry and surface radon surveys, geological mapping, and airborne geophysics, all of which will be used to assist in defining drill targets.

At the end of 2012, African Energy Resources concluded baseline environmental studies for the Chirundu Uranium Project, which was the only work completed by African Energy on its sandstone uranium projects. The Chirundu Project near the Zimbabwe border is focused on exploring the Njame and Gwabe deposits and reports 4 270 tU as measured, indicated and inferred resources. A mining licence was granted for the project in October 2009, with a view to develop a 500 tU/yr acid heap leach operation. It includes the Siamboka prospect. A feasibility study was commenced but then deferred because of low uranium prices. The company was also exploring the Chisebuka deposit, 250 km along strike south-west.

In June 2016, GoviEx Uranium Inc. acquired Denison's Mutanga Project, and in October 2017 completed the acquisition of Africa Energy's Chirundu Uranium Project, consolidating these adjacent projects. In 2017, GoviEx released a new preliminary economic assessment for the Mutanga uranium project, including the mineral resource estimate for Mutanga, Dibwe, Dibwe East, Gwabe, Njame and Njame South sandstone-hosted ore deposits. The project currently consists of five main uranium deposits under three fully permitted contiguous mining licences, totalling 140 km in strike length. It also includes two more prospective licences covering 100 km^2.

Due to the COVID-19 pandemic, GoviEx employees worked remotely in 2020. In 2021, GoviEx planned soil sampling and geological mapping in the Mutanga area. GoviEx has also planned an 8 000 m downhole percussion drilling programme (100 m x 50 m grid), focused on the Dibwe East deposit and new areas defined by previous trench sampling east of Dibwe East.

In 2017 and 2018, exploration expenditures by GoviEx amounted to USD 710 000 and USD 607 000, respectively. In 2019 and 2020, exploration expenditures amounted to USD 502 000 and USD 536 000, respectively.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

In October 2017, GoviEx published an NI 43-101 technical report on a preliminary economic assessment of the Mutanga Project. GoviEx's Mutanga and Chirundu deposits are estimated to hold 21.6 Mt of measured ore resources grading 269 ppm U (0.0269% U) and containing 5 810 tU. Inferred resources are estimated to be 74.6 Mt of ore grading 231 ppm U (0.0231% U) and containing 17 270 tU. A mineral reserve has yet to be evaluated for the project.

The Lumwana copper mine, where resources are hosted by mica-quartz-kyanite schists of the Katangan Supergroup, contains identified recoverable resources of 6 967 tU. Potential for the discovery of additional uranium resources exists in various parts of the country that have been poorly explored. Of particular interest is the Copperbelt, where many copper orebodies are associated with uranium mineralisation.

Uranium production

Historical review

A total of 102 tU_3O_8 (86 tU) was produced at the Mindola mine in Kitwe during the late 1950s. Production ceased in 1960 and no uranium has been produced since.

Uraniferous ore is stockpiled at Lumwana while mining the higher-grade Malundwe copper deposit. As of May, 2019, the stockpile amounted to 4 Mt of ore grading at 910 ppm U (3 640 tU).

Future projects

GoviEx is planning to develop a USD 123 million project at Mutanga and Chirundu with estimated cash operating costs of USD 31.1/lb U_3O_8 (USD 80.85/kgU), excluding royalties, when uranium prices have improved to >USD 55/lb U_3O_8 (USD 143/kgU). Following a successful licence renewal, a preliminary economic study of the Mutanga deposit was undertaken for an open-pit mine with acid heap leaching. Most of the mineralisation occurs within 125 m of surface and is considered to have a reasonable prospect for economic mining. The project holds a 25-year mining licence, environmental approval, and a radioactive materials licence. The project is forecast to produce 920 tU/yr for 11 years.

On 25 June 2020, the Mining Cadastre Department of Zambia issued a letter to GoviEx revoking the Chirundu mining permit due to failure to develop the permitted mining areas and carry out mining operations. However, on 10 May 2021, the Chirundu mining permit was reinstalled subject to the completion of exploration and development milestones to advance the project towards a feasibility study.

Uranium production centre technical details

(as of 1 January 2021)

	Centre #1	Centre #2
Name of production centre	Lumwana	Mutanga
Production centre classification	Planned	Planned
Date of first production (year)	NA	NA
Source of ore:		
Deposit name(s)	Malundwe-Chimiwungo	Dibwe-Mutanga-Gwabe-Njame
Deposit type(s)	Metasomatic (metamorphosed schists)	Sandstone
Recoverable resources (tU)	6 967	20 311
Grade (% U)	0.07	0.033
Mining operation:		
Type (OP/UG/ISL)	OP	OP
Size (tonnes ore/day)	2 800	11 000
Average mining recovery (%)	NA	NA
Processing plant:		
Acid/alkaline	Acid	Acid
Type (IX/SX/HL)	SX	HL
Size (tonnes ore/day)		
Average process recovery (%)	93.1	88.0
Nominal production capacity (tU/year)	650	920
Plans for expansion (yes/no)		
Other remarks	Mine currently operated by Barrick	Mine construction on hold until uranium price increases

Environmental activities and socio-cultural issues

Waste rock management

Equinox Minerals' original plan in 2003 was to excavate, stockpile and return the uraniferous ore to the Malundwe pit at the Lumwana copper mine, following completion of mining, as it was considered uneconomic at the time to recover the uranium. However, in 2006, with a uranium spot price in excess of USD 50 lb/U_3O_8 (USD 130/kgU), the project was re-evaluated. In January 2011, Equinox Minerals reported that the portion of the stockpile containing 0.09% U and 0.8% Cu could be treated at a later date, if and when a uranium plant is built. The stockpile is currently classified and expensed as "waste" in the copper project.

In May 2019, Lumwana Mining Company (LMC) presented an Environmental and Socioeconomic Impact Assessment (ESIA) Report for the proposed Stockpile Reclamation Project within the Lumwana Mining Licences. LMC has been mining from the Malundwe open pit since 2007. Initially, LMC investigated the feasibility of processing the stockpile for both copper and uranium. The uranium project was shelved in 2009/2010 following the decline of the uranium price and low availability of uranium ore. The proposed stockpile for reclamation covers an area of approximately 148 000 m^2 and contains about 4 Mt of "ore". The stockpiles contain about 0.5% sulphur, 0.79% copper and 920 ppm uranium (3 640 tU). The Chimuwungo resource contains less than 0.5% of copper and less than 200 ppm of uranium.

Environmental activities and socio-cultural issues

The Mines and Minerals Development Act (1995) makes provision for the preparation of a project brief when applying for a mining licence. This must include an environmental impact statement detailing all potential impacts of the project. Annual environmental audits must be carried out to ensure compliance and contributions must be made to an environmental management fund for rehabilitation.

Local inhabitants around the Mutanga Project were involved in public hearings organised by the Environmental Council of Zambia. Agreements were reached regarding the displacement of 107 families in two villages to allow for the construction of the mine infrastructure.

Denison/GoviEx has been providing funding to several communities and sustainability projects including the construction of schools and clinics, water boreholes, and agricultural programmes.

African Energy assisted with the construction of a community health post and completed a water borehole at Sikoongo Village near their Chirundu Project.

Barrick invested in a wide range of sustainable development initiatives in 2012, including funding for infrastructures (such as schools and health centres), literacy and agricultural programmes, community sports and recreation, and an initiative to provide microcredit and small business loans to women.

Uranium requirements

Zambia has no nuclear generating capacity. In May 2016, Russia's Rosatom signed an intergovernmental agreement on co-operation in the peaceful uses of nuclear energy, which provides a framework for opportunities to construct nuclear power facilities. Further co-operation agreements were signed with Rosatom in December 2016 and in June 2017. The first is for the training of Zambian specialists in Russia so that within 15 years, Russia will assist Zambia with training young nuclear energy engineers, plan for nuclear power plant personnel, develop a nuclear energy regulator and build a research reactor. Zambia aims to become a regional centre for nuclear medicine. With respect to energy, nuclear power is needed to prevent load shedding due to unreliable supply.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Mining activities, in general, were regulated by the Mines and Minerals Act (1995), but until recently there was no legislation specifically relating to the exploration and mining of uranium. The act was repealed in 2008 following widespread criticism of what was perceived to be excessive scope for granting tax concessions. This act was replaced by the Mines and Minerals Development Act 2008, which ruled that no special agreements should be entered into by the government for the development of large-scale mining licences. It also effectively ended development agreements concluded under the previous act. The Mines and Minerals Development (Prospecting, Mining, and Milling of Uranium Ores and Other Radioactive Mineral Ores) and Regulations of 2008 deal with the mining, storage and export of uranium. Mining and export licences will only be granted when the Radiation Protection Authority is satisfied that the operations pose no environmental and health hazards. Applicants for export licences will also have to prove the authenticity of the importers in terms of International Atomic Energy Agency (IAEA) guidelines.

A study by the Council of Churches concluded that current legislation and enforcement was inadequate for uranium mining. It recommended that current regulations be revised to address the concerns of local communities and that education and awareness programmes be initiated prior to any uranium exploration and mining activities.

In 2011, Zambia and Finland signed co-operation projects aimed at helping the southern African nation review regulations on uranium mining as well as the management of the mineral. The two projects are aimed at evaluating current regulations on uranium and other radioactive minerals as well as developing a modern geographical information infrastructure. These projects are designed to help the country evaluate, update and review regulations regarding the safety of uranium mining.

Zambia has upgraded its mining legislation to include uranium, following detailed consultations with the IAEA. It started issuing uranium mining licences late in 2008, and in 2017 was undertaking a further revision of regulations regarding uranium exploration and mining.

Reasonably assured conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	12 777	12 777	88-93
Total	0	0	12 777	12 777	88-93

Reasonably assured conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	12 777	12 777	88-93
Total	0	0	12 777	12 777	88-93

Reasonably assured conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	5 810	5 810
Metasomatite	0	0	6 967	6 967
Total	0	0	12 777	12 777

Inferred conventional resources by production method

(recoverable tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	18 221	18 221	88-93
Total	0	0	18 221	18 221	88-93

Inferred conventional resources by processing method

(recoverable tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	18 221	18 221	88-93
Total	0	0	18 221	18 221	88-93

Inferred conventional resources by deposit type

(recoverable tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	17 270	17 270
Metasomatite	0		951	951
Total	0	0	18 221	18 221

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Underground mining[1]	86	0	0	86	0
Total	86	0	0	86	0

1. Pre-2018 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Conventional	86	0	0	86	0
Total	86	0	0	86	0

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2018	2019	2020	Total through end of 2020	2021 (expected)
Metasomatite	86	0	0	86	0
Total	86	0	0	86	0

Short-term production capabilities

(tonnes U/year)

2025				2030			
A-I	A-I	B-I	A-II	B-II	B-I	A-II	B-II
0	0	0	0	NA	0	0	NA

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	0	NA	0	0	0	NA

Appendix 1. List of reporting organisations and contact persons

NEA	OECD Nuclear Energy Agency – Division of Nuclear Technology Development and Economics, Paris Contact person: Mr Franco Michel-Sendis (Scientific Secretary)
IAEA	International Atomic Energy Agency, Division of Nuclear Fuel Cycle and Waste Technology, Vienna Contact person: Mr Mark Mihalasky (Scientific Secretary)
Algeria	Commissariat à l'Energie Atomique (COMENA), Centre de Recherche Nucléaire de Draria, BP 43, Sebala, Draria,- Alger 16003 Algérie Contact person: Mr Jamel Eddine Nacer
Argentina	Comisión Nacional de Energía Atómica (CNEA), División Gestión de Proyectos, Avenida del Libertador 8250, (C1429BNP) Ciudad, Buenos Aires Contact person: Mr Luis López
Armenia	Ministry Territorial Administration and Infrastructure, Energy Department, Atomic Energy Division, Government House 3, Republic Square, Yerevan Contact person: Ms Margarita Balayan
Australia	Geoscience Australia, GPO Box 378, Canberra, ACT 2601 Contact person: Mr Andrew Cross
	Department for Energy and Mining, Government of South Australia, GPO Box 320, Adelaide, SA 5001 Contact person: Mr Adrian Fabris
Bangladesh	Institute of Nuclear Minerals (IBN), Bangladesh Atomic Energy Commission, Atomic Energy Research Establishment, Ganakbari, Savar-1349, Dhaka Contact person: Mr Golam Rasul
Belgium	Service Public Fédéral – Économie, PME, Classes Moyennes & Énergie, 16 Bd du Roi Albert II, 1000 Brussels Contact persons: Mr Alberto Fernandez Fernandez, Ms Françoise Renneboog (Synatom)
Bolivia	Servicio Geológico Minero (SERGEOMIN), Jefatura Unidad de Prospección, Calle Federico Suazo No. 1673, Esquina Reyes Ortiz, La Paz Contact persons: Mr Hernan Mamani, Mr Mario Barragan, Mr German Colque Llampa
	Agencia Boliviana de Energía Nuclear (ABEN), Unidad de Materia Primas Radiactivas, Calle 22 Calacoto, La Paz Contact person: Ms Hortensia Jimenez
	Autoridad de Fiscalización de Electricidad y Tecnología Nuclear (AETN), Dirección de Tecnología Nuclear, Av. 16 de Julio No. 1571, La Paz Contact person: Mr Rubens Barbeito

Brazil	Indústrias Núcleares do Brasil S/A (INB), 230 Republica Do Chile Av. 25 Floor, Rio de Janeiro Contact person: Mr Luiz Filipe da Silva
Canada	Natural Resources Canada, Uranium and Radioactive Waste Division, 580 Booth Street, Ottawa, Ontario K1A OE4 Contact person: Mr Tom Calvert
Chile	Comisión Chilena de Energía Nuclear, División Investigación en Aplicaciones Nucleares, Departamento de Materiales Avanzados, Centro Nuclear Lo Aguirre, Ruta 68, Km 20, Región Metropolitana Contact person: Mr Jaime Salas Kurte
Czech Republic	DIAMO s.p., Máchova 201, 471 27 Stráž pod Ralskem, CĚZ, a.s., Nuclear Fuel Cycle Section Duhová 2/1911, 14053 Praha 4 Contact person: Mr Pavel Vostarek
Denmark/ Greenland	Geological Survey of Denmark and Greenland, Øster Volgade 10, 1350 Copenhagen, Denmark Contact person: Ms Kristine Thrane
Ecuador	Geological and Energy Research Institute (IIGE), Innovation Directorate, Sky Building, Planta Baja, Av, de la República E7-263, Quito Contact person: Francisco Herrera
Egypt	Nuclear Materials Authority of Egypt, P.O. Box 530, El-Maadi, Cairo Contact persons: Mr Hamid Ibrahim Mira, Mr Amer Hussien Amer Bishr
Finland	Ministry of Economic Affairs and Employment, Energy Department, Geological Survey of Finland, Vuorimiehentie 5 P.O. Box 96, FI-02151, Espoo Contact person: Mr Esa Pohjolainen
France	Commissariat à l’énergie atomique et aux énergies alternatives (CEA), Centre de Saclay, 91191 Gif-sur-Yvette Cedex Contact person: Ms Sophie Gabriel
Germany	Federal Institute for Geosciences and Natural Resources (BGR), Stilleweg 2, D-30655 Hannover Contact person: Mr Michael Schauer
Guyana	Guyana Geology and Mines Commission, Main Office, Upper Brickdam, Georgetown Contact persons: Xiomara Griffith, Amanda O’Neil
Hungary	Mining and Geological Survey of Hungary, 17-23 Columbus Street, H-1145 Budapest (in care of the Hungarian Atomic Energy Authority, 4 Fényes Adolf Street, H-1036 Budapest) Contact person: Mr András Barabás
India	Atomic Minerals Directorate for Exploration and Research (AMD), Department of Atomic Energy (DAE), AMD Complex, 1-10-153-156, Begumpet, Hyderabad 500 016, Telangana Contact person: Mr Deepak Kumar Sinha
Indonesia	Badan Tenaga Nuklir Nasional, Jalan Kuningan Barat, Mampang Prapatan, Jakarta 12710 Contact persons: Mr Yarianto Sugeng Budi Susilo, Mr Heri Syaeful

Iran, Islamic Republic of	Atomic Energy Organisation of Iran, North Karegar Av., P.O. Box 14155-1339, Tehran Contact persons: Mr Mohammed Ghaderi, Mr G. Raisali (National Liaison Officer)
Japan	Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI), Nuclear Energy Policy Planning Division, 1-3-1 Kasumigaseki, Chiyoda-ku, Tokyo Contact persons: Ms Nozomi Ehara
	Japan Oil, Gas and Metals National Corporation (JOGMEC), Exploration Division 3, Metals Exploration Department, Toranomon Twin Building 2-10-1 Toranomon, Minato-ku, Tokyo Contact persons: Mr Yuu Kawakami
Jordan	Jordan Uranium Mining Company (JUMCO), Almadina Street No. 269, Amman 11953 Contact person: Mr Mohammad Al-Shannag
Kazakhstan	National Atomic Company Kazatomprom JSC NAC, 17/12, Syganak Street, Z05T1X3 Nur-Sultan Contact person: Ms Aliya Akzholova
Madagascar	Office des Mines Nationales et des Industries Strategiques (OMNIS), 21, Làlana Razanakombana Ambohijatovo, Antananarivo 101 Contact person: Ms Dinamalala Julia Ranaivosaona
Malawi	Atomic Energy Regulatory Authority (AERA), Chief M'Mbelwa Building, Robert Mugabe Crescent, City Center, Lilongwe 3 Contact person: Mr Master Simoni
	Ministry of Mining (MM), Department of Mines, Matamando House, City Center, Lilongwe Contact person: Mr Chimwemwe Bandazi
Mali	Direction Nationale de la Geologie et des Mines du Mali (DNGM), Division Geologie, District de Bamako, Commune I, Quartier Sotuba, Route du 3ème Pont, BP : 223 Contact person: Mr Karim Diarra
Mexico	Servicio Geológico Mexicano, Boulevard Felipe Ángeles S/N Km. 93.5, Colonia Venta Prieta, 42080, Pachuca Hidalgo Contact person: Mr Francisco José Escandón Valle (deceased 2021)
	Instituto Nacional de Investigaciones Nucleares (ININ), km. 36.5 de la Carretera México-Toluca s/n, La Marquesa municipio de Ocoyoacac Contact person: Ms Verónica Badillo Almaraz
Mongolia	Mineral Resources and Petroleum Authority (MRPA), Government building XII, Chingeltei district, Barilgachdin talbai-3, Ulaanbaatar 15170 Contact persons: Ms Tamiraa Altangerel, Mr Mungunkhuu Enkhmunkh
	Nuclear Energy Commission (NEC), Uildverchdiin street 2, 2nd Khoroo, Khan-Uul District, Ulaanbaatar 17032 Contact persons: Mr Baatartsogt Baldorj, Mr Tuvshinbayar Olonbayar
Namibia	Ministry of Mines and Energy, Department of Mines, 6 Aviation Road, Windhoek Contact persons: Ms Helena Itamba, Mr Erasmus Shivolo

Paraguay	Viceministerio de Minas y Energía, Dirección de Recursos Energéticos Primarios (DRE) & Dirección de Recursos Minerales (DRM), MFRH+4Q3, Ñangapiry y Los Rosales, San Lorenzo Contact persons: Mr Felipe R. Mitjans A. (DRE), Ms Mónica Urbieta (DRM)
Peru	Instituto Geológico, Minero y Metalúrgico (INGEMMET), 1470 Canada Av., San Borja, Lima 15034 Contact person: Mr Michael Valencia Muñoz
Poland	Ministry of Climate and Environment, Nuclear Energy Department, 52/54 Wawelska Street, 00-922 Warsaw Contact person: Mr Andrzej Chwas
Portugal	Direção Geral de Energia e Geologia, Direção de Serviços de Minas e Pedreiras, Avenida 5 de Outubro, 1069-203 Lisboa Contact person: Mr José Silva Pereira
Russia	Uranium One, Sredny Ovchninkovsky 4, bld 1, Moscow, Russia, 115184 Contact person: Mr Alexander Boytsov
Saudi Arabia	King Abdullah City for Atomic and Renewable Energy (K.A.CARE), Atomic Energy Sector, Nuclear Fuel Cycle Program, Riyadh Contact person: Mr Sharaf Al Sharif
Senegal	Ministry of Energy and Mining, Regulatory Body, Experts Comity, Allée Papa Gueye Fall, Immeuble Adja Fatou Nourou Diop, Dakar Contact person: Mr Mamadou Kanoute
Slovakia	Štátny geologický ústav Dionýza Štúra, Mlynská dolina 1, 817 04 Bratislava 11 Contact persons: Mr Dušan Kúšik, Mr Stanislav Šoltés
Slovenia	Administration of the Republic of Slovenia for Nuclear Safety, Litostrojska cesta 54, 1000 Ljubljana Contact person: Ms Vesna Logar Zorn
Spain	ENUSA Industrias Avanzadas, S. A. S.M.E., Santiago Rusiñol, 12, E- 28040, Madrid Contact person: Ms Lourdes Guzmán
Türkiye	Ministry of Energy and Natural Resources, Nuclear Energy Project Implementation Department, Nasuh Akar Mah. Türkocaği Cad. No: 2, 06520 Çankaya, Ankara Contact persons: Mr Salih Sari, Ms Cisem Unaldi
Ukraine	State Enterprise Kirovgeology, State Service of Geology and Resources, Ministry of Ecology and Natural Resources of Ukraine, 8/9 Kikvidze Street., Kiev 01103 Contact persons: Mr Yuri Bakarzhiyev, Mr Anatoliy Bakarzhiyev
	Ministry of Energy and Coal Industry of Ukraine, 30 Khreschatyk Street, Kiev 01601, MCP, Ukraine Contact person: Mr Oleksandr Shust
United States	Energy Information Administration, US Department of Energy, Washington, D.C. 20585 Contact persons: Mr Slade Johnson, Ms Katherine Antonio, Mr Tim Shear
	US Geological Survey, Denver Federal Center, Denver, Colorado 80225 Contact person: Ms Susan Hall

Uzbekistan	Navoi Mining and Metallurgical Combinat State Enterprise, Navoi street-27, Navoi Contact person: Mr Umid Mavlanovich Fayziev
	State Committee on Industrial Safety (Goskomprombez), 100011, Tashkent Street, M-14, 27-uy, Tashkent Contact person: Mr Ibragim Tashkentbaev
Viet Nam	Institute for Technology of Radioactive and Rare Elements (ITTRRE), Vietnam Atomic Energy Institute (VNATOM), 48 Langha Street, Dongda District, Hanoi Contact person: Mr Nguyen Trong Hung

Appendix 2. Members of the Joint NEA-IAEA Uranium Group participating in 2020-2022 meetings

NEA	Ms Luminita Grancea (*Scientific Secretary*)	Division of Nuclear Technology Development and Economics, Paris
NEA	Mr. Franco Michel-Sendis (*Scientific Secretary*)	Division of Nuclear Technology Development and Economics, Paris
IAEA	Mr Mark Mihalasky *(Scientific Secretary)*	Division of Nuclear Fuel Cycle and Waste Technology, Vienna
Algeria	Mr Jamel Eddine Nacer (Researcher)	Centre de Recherche Nucléaire de Draria, Draria
Argentina	Mr Luis Eduardo López (Geologist, Raw Materials Exploration Manager)	Comisión Nacional de Energía Atómica, Buenos Aires
Australia	Mr Andrew Cross (Senior Commodity Specialist, Resources Advice and Promotion)	Geoscience Australia, Canberra
Belgium	Ms Françoise Renneboog (Head of Market Analysis Division, Fuel Supply Department)	SYNATOM Market Analysis Division, Brussels
Bolivia, Plurinational State of	Mr Rubens Barbeito Reyes (Director of Nuclear Technology)	Autoridad de Fiscalización de Electricidad y Tecnología Nuclear de Bolivia, La Paz
Brazil	Mr Luiz Filipe Da Silva (President's Advisor)	Indústrias Nucleares do Brasil, Mineral Resources and Production, Rio de Janeiro
Canada	Mr Harold Thomas Calvert (Senior Policy Advisor, Uranium and Radioactive Waste Division; Uranium Group Vice Chair)	Natural Resources Canada, Uranium and Radioactive Waste Division, Ontario

Canada	Mr Jamie Fairchild (Senior Advisor)	Natural Resources Canada, Uranium and Radioactive Waste Division, Ontario
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Mongolia	Ms Baatartsogt Baldorj (Head of the Administrative Office of the Executive office)	Nuclear Energy Commission Mongolia, Ulaanbaatar
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Appendix 3. Glossary of definitions and terminology

Units

Metric units are used in all tabulations and statements. Resources and production quantities are expressed in terms of tonnes (t) contained uranium (U) rather than uranium oxide (U_3O_8).

1 short ton U_3O_8	=	0.769 tU
1% U_3O_8	=	0.848% U
1 USD/lb U_3O_8	=	USD 2.6/kg U
1 tonne	=	1 metric ton

Resource terminology

Resource estimates are divided into separate categories reflecting different levels of confidence in the quantities reported. The resources are further separated into categories based on the cost of production.

Definitions of resource categories

Uranium resources are broadly classified as either conventional or unconventional. Conventional resources are those that have an established history of production where uranium is a primary product, co-product or an important by-product (e.g., from the mining of copper and gold). Very low-grade resources or those from which uranium is only recoverable as a minor by-product are considered unconventional resources.

Conventional resources, as well as unconventional resources when sufficient data are available, are further divided according to different confidence levels of occurrence into four categories:

1. Reasonably assured resources (RAR)
2. Inferred resources (IR)
3. Prognosticated resources (PR)
4. Speculative resources (SR)

The correlation between these resource categories and those used in selected national resource classification systems is shown in Figure A3.1.

Reasonably assured resources (RAR) refers to uranium that occurs in known mineral deposits of delineated size, grade and configuration such that the quantities, which could be recovered within the given production cost ranges with currently proven mining and processing technology, can be specified. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics. Reasonably assured resources have a high assurance of existence. Unless otherwise noted, RAR are expressed in terms of quantities of uranium recoverable from mineable ore (see: recoverable resources).

Inferred resources (IR) refers to uranium, in addition to RAR, that is inferred to occur based on direct geological evidence, in extensions of well-explored deposits, or in deposits in which geological continuity has been established but where specific data, including measurements of the deposits, and knowledge of the deposit's characteristics, are considered to be inadequate to classify the resource as RAR. Estimates of tonnage, grade and cost of further delineation and recovery are based on such sampling as is available and on knowledge of the deposit characteristics as determined in the best known parts of the deposit or in similar deposits. Less reliance can be placed on the estimates in this category than on those for RAR. Unless otherwise noted, inferred resources are expressed in terms of quantities of uranium recoverable from mineable ore (see: recoverable resources).

Figure A3.1. **Approximate correlation of terms used in major resources classification systems**

	Identified resources			Undiscovered resources		
NEA/IAEA	Reasonably assured		Inferred	Prognosticated	Speculative	
Australia	Demonstrated		Inferred	Undiscovered		
	Measured	Indicated				
Canada (NRCan)	Measured	Indicated	Inferred	Prognosticated	Speculative	
United States (DOE, USGS)	Reasonably assured		Inferred	Undiscovered		
Russia, Kazakhstan, Ukraine, Uzbekistan	A + B + C1	C2	C2+P1	P1	P2	P3

The terms illustrated are not strictly comparable as the criteria used in the various systems are not identical. "Grey zones" in correlation are therefore unavoidable, particularly as the resources become less assured. Nonetheless, the chart presents a reasonable approximation of the comparability of terms.

Work to align the NEA/IAEA and national resource classification systems outlined above with the United Nations Framework Classification system remains under consideration. (For a summary of recent efforts, see: www.unece.org/fileadmin/DAM/energy/se/pdfs/egrc/egrc5_apr2014/ECE.ENERGY.GE.3.2014.L1_e.pdf)

Prognosticated resources (PR) refers to uranium, in addition to inferred resources, that is expected to occur in deposits for which the evidence is mainly indirect and which are believed to exist in well-defined geological trends or areas of mineralisation with known deposits. Estimates of tonnage, grade and cost of discovery, delineation and recovery are based primarily on knowledge of deposit characteristics in known deposits within the respective trends or areas and on such sampling, geological, geophysical or geochemical evidence as may be available. Less reliance can be placed on the estimates in this category than on those for inferred resources. Prognosticated resources are normally expressed in terms of uranium contained in mineable ore (i.e., in situ quantities).

Speculative resources (SR) refers to uranium, in addition to prognosticated resources, that is thought to exist, mostly on the basis of indirect evidence and geological extrapolations, in deposits discoverable with existing exploration techniques. The location of deposits envisaged in this category could generally be specified only as being somewhere within a given region or geological trend. As the term implies, the existence and size of such resources are speculative. SR are normally expressed in terms of uranium contained in mineable ore (i.e., in situ quantities).

Cost categories

The cost categories, in United States dollars (USD), used in this report are defined as: <USD 40/kgU (<USD 15/lbs U_3O_8), <USD 80/kgU (<USD 30/lbs U_3O_8), <USD 130/kgU (<USD 50/lbs U_3O_8), and <USD 260/kgU (<USD 100/lbs U_3O_8). The resource tonnages across the cost categories are cumulative, from lowest cost to highest cost category. This means that uranium resource tonnage for any cost category also includes uranium resource tonnage from the lower cost categories:

- Resources categorised at <USD 40/kgU are the lowest cost, most economically attractive to recover.
- Resources categorised at <USD 80/kgU include those recoverable at <USD 40/kgU, plus resources that are more expensive to recover, up to USD 80/kgU.
- Resources categorised at <USD 130/kgU include those recoverable at <USD 80/kgU and <USD 40/kgU, plus resources that are more expensive to recover, up to USD 130/kgU.
- Resources categorised at <USD 260/kgU include those recoverable at all lower cost categories, plus resources that are more expensive, up to USD 260/kgU.

All resource categories are defined in terms of costs of uranium recovered at the ore processing plant.

Note: It is not intended that the cost categories should follow fluctuations in market conditions.

Conversion of costs from other currencies into USD is done using an average exchange rate for the month of June in that year except for the projected costs for the year of the report.

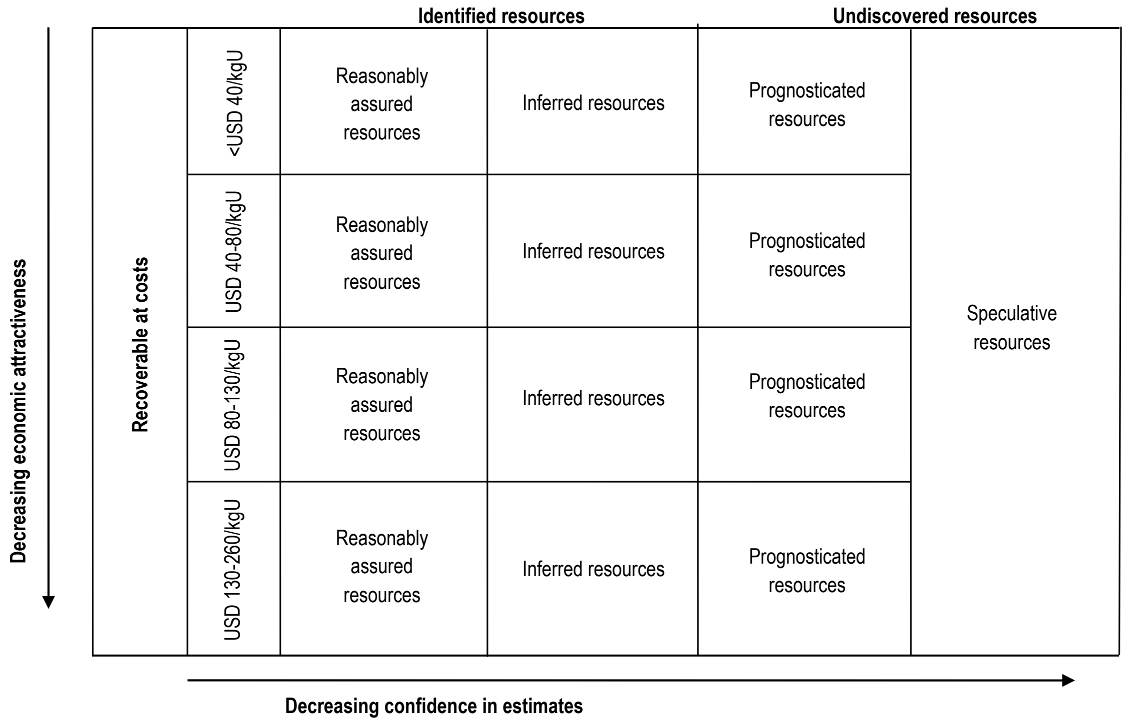
When estimating the cost of production for assigning resources within these cost categories, account has been taken of the following costs:

- the direct costs of mining, transporting and processing the uranium ore;
- the costs of associated environmental and waste management during and after mining;
- the costs of maintaining non-operating production units where applicable;
- in the case of ongoing projects, those capital costs that remain non-amortised;
- the capital cost of providing new production units where applicable, including the cost of financing;
- indirect costs such as office overheads, taxes and royalties where applicable;
- future exploration and development costs wherever required for further ore delineation to the stage where it is ready to be mined;
- sunk costs are not normally taken into consideration.

Relationship between resource categories

Figure A3.2 illustrates the inter-relationship between the different resource categories. The horizontal axis expresses the level of assurance about the actual existence of a given tonnage based on varying degrees of geologic knowledge while the vertical axis expresses the economic feasibility of exploitation by the division into cost categories.

Figure A3.2. **NEA/IAEA classification scheme for uranium resources**



Recoverable resources

RAR and IR estimates are expressed in terms of recoverable tonnes of uranium (i.e., quantities of uranium recoverable from mineable ore), as opposed to quantities contained in mineable ore, or quantities in situ (i.e., not taking into account mining and milling losses). Therefore, both expected mining and ore processing losses have been deducted in most cases. If a country reports its resources as in situ and the country does not provide a recovery factor, the NEA/IAEA assigns a recovery factor to those resources based on geology and projected mining and processing methods to determine recoverable resources. The recovery factors that have been applied are:

Mining and milling method	Overall recovery factor (%)
Open-pit mining with conventional milling	80
Underground mining with conventional milling	75
In situ leaching (acid)	85
In situ leaching (alkaline)	70
Heap leaching	70
Block and stope leaching	75
Co-product or by-product	65
Unspecified method	75

Secondary sources of uranium terminology

Mixed oxide fuel (MOX): MOX is the abbreviation for a fuel for nuclear power plants that consists of a mixture of uranium oxide and plutonium oxide. Current practice is to use a mixture of depleted uranium oxide and plutonium oxide.

Depleted uranium: Uranium where the ^{235}U assay is below the naturally occurring 0.7110%. Natural uranium is a mixture of three isotopes, uranium-238 – accounting for 99.2836%, uranium-235 – 0.7110%, and uranium-234 – 0.0054%. Depleted uranium is a by-product of the enrichment process, where enriched uranium is produced from initial natural uranium feed material.

Production terminology [1]

Production centres

A production centre, as referred to in this report, is a production unit consisting of one or more ore processing plants, one or more associated mines and uranium resources that are tributary to these facilities. For the purpose of describing production centres, they have been divided into four classes, as follows:

- Existing production centres are those that currently exist in operational condition. Production projections continue until the identified resources (costs < USD 130/kgU) are exhausted.
- Committed production centres are those that are either under construction or are firmly committed for construction.
- Planned production centres are those for which feasibility studies are completed and regulatory approvals are at advanced stage.
- Prospective production centres are those for which some level of feasibility study has been completed and the centres are supported by tributary RAR and Inferred resources. Indicative start-up dates should have been announced.

Production, production capacity, and production capability

Production: Denotes the amount of uranium output, in tonnes U contained in concentrate, from an ore processing plant or production centre (with milling losses deducted).

Production capacity: Denotes the nominal level of output, based on the design of the plant and facilities over an extended period, under normal commercial operating practices.

Production capability: Refers to an estimate of the level of production that could be practically and realistically achieved under favourable circumstances from the plant and facilities at any of the types of production centres described above, given the nature of mined ore flow to them. Projections of production capability are supported only by RAR and/or IR. The projection is presented based on those resources recoverable at costs <USD 130/kgU.

Mining and milling

Open-pit mining: The extraction of near-surface uranium-bearing rock (ore) from an exposed pit open to the air, typically excavated as a series of benches or steps cut into the pit walls using drilling, blasting, and heavy machinery.

1. IAEA (1984), *Manual on the Projection of Uranium Production Capability,* General Guidelines, Technical Report Series No. 238, IAEA, Vienna.

Underground mining: The extraction beneath the surface of uranium-bearing rock (ore) through horizontal, sub-horizontal, and vertical tunnels (shafts, slopes, adits, declines and other openings that access the ore body) using drilling, blasting, and various types of specialized heavy machinery. More commonly applied to high-grade, low-tonnage deposits where the ore body is too deep to be mined economically by open pit methods.

In situ leaching mining (ISL, sometimes referred to as in situ recovery, or ISR): The extraction of uranium from sandstone using chemical solutions and the recovery of uranium at the surface. ISL extraction is conducted by injecting a suitable uranium-dissolving leach solution (acid or alkaline) into the ore zone below the water table thereby oxidising, complexing and mobilising the uranium; then recovering the pregnant solutions through production wells, and finally pumping the uranium bearing solution to the surface for further processing.

Heap leaching (HL): Heaps of ore are formed over a collecting system underlain by an impervious membrane. Dilute sulphuric acid solutions are distributed over the top surface of the ore. As the solutions seep down through the heap, they dissolve a significant (50-75%) amount of the uranium in the ore. The uranium is recovered from the heap leach product liquor by ion exchange or solvent extraction.

In-place leaching (IPL): involves leaching of broken ore without removing it from an underground mine. This is also sometimes referred to as stope leaching or block leaching.

Co-product: Uranium is a co-product when it is one of two commodities that must be produced to make a mine economic. Both commodities influence output, for example, uranium and copper are co-produced at Olympic Dam in Australia. Co-product uranium is produced using either the open-pit or underground mining methods.

By-product: Uranium is considered a by-product when it is a secondary or additional product. By-product uranium can be produced in association with a main product or with co-products (e.g., uranium recovered from the Palabora copper mining operations in South Africa). By-product uranium is produced using either the open-pit or underground mining methods.

Uranium from phosphate rocks: Uranium has been recovered as a by-product of phosphoric acid production. Uranium is separated from phosphoric acid by a solvent extraction process. The most frequently used reagent is a synergetic mixture of tri-n-octyl phosphine oxide (TOPO) and di 2-ethylhexyl phosphoric acid (DEPA).

Ion exchange (IX): Reversible exchange of ions contained in a host material for different ions in solution without destruction of the host material or disturbance of electrical neutrality. The process is accomplished by diffusion and occurs typically in crystals possessing – one or two – dimensional channels where ions are weakly bonded. It also occurs in resins consisting of three-dimensional hydrocarbon networks to which are attached many ionisable groups. Ion exchange is used for recovering uranium from leaching solutions.

Solvent extraction (SX): A method of separation in which a generally aqueous solution is mixed with an immiscible solvent to transfer one or more components into the solvent. This method is used to recover uranium from leaching solutions.

Idled mine: A temporarily closed operation. Idled mines are those with associated identified uranium resources and processing facilities that have all necessary licenses, permits and agreements for operation and have produced commercially in the past, but were not producing as of the middle to end of the second year of the current Red Book reporting period. Annual production capacity of an idled mine could be potentially increased relatively rapidly if the operation is brought back into service. Although each mine operation is unique in terms of operational costs and a threshold price for reopening, the ability to raise capital as required to resume operation and to meet regulatory requirements, idled mines could be returned to production in roughly one year, given that all permits and licences remain in place.

Demand terminology

Reactor-related requirements: Refers to natural uranium acquisitions *not* necessarily consumption during a calendar year.

Environmental terminology[2]

Close-out: In the context of uranium mill tailings impoundment, the operational, regulatory and administrative actions required to place a tailings impoundment into long-term conditions such that little or no future surveillance and maintenance are required.

Decommissioning: Actions taken at the end of the operating life of a uranium mill or other uranium facility in retiring it from service with adequate regard for the health and safety of workers and members of the public and protection of the environment. The time period to achieve decommissioning may range from a few to several hundred years.

Decontamination: The removal or reduction of radioactive or toxic chemical contamination using physical, chemical, or biological processes.

Dismantling: The disassembly and removal of any structure, system or component during decommissioning. Dismantling may be performed immediately after permanent retirement of a mine or mill facility or may be deferred.

Environmental restoration: Clean-up and restoration, according to predefined criteria, of sites contaminated with radioactive and/or hazardous substances during past uranium production activities.

Environmental impact statement: A set of documents recording the results of an evaluation of the physical, ecological, cultural and socio-economic effects of a planned installation, facility, or technology.

Groundwater restoration: The process of returning affected groundwater to acceptable quality and quantity levels for future use.

Reclamation: The process of restoring a site to predefined conditions, which allows new uses.

Restricted release (or use): A designation, by the regulatory body of a country, that restricts the release or use of equipment, buildings, materials or the site because of its potential radiological or other hazards.

Tailings: The remaining portion of a metal-bearing ore consisting of finely ground rock and process liquids after some or all of the metal, such as uranium, has been extracted.

Tailings impoundment: A structure in which the tailings are deposited to prevent their release into the environment.

Unrestricted release (or use): A designation, by the regulatory body of a country, that enables the release or use of equipment, buildings, materials or the site without any restriction.

Geological terminology

Uranium occurrence: A naturally occurring, anomalous concentration of uranium.

Uranium deposit: A mass of naturally occurring mineral from which uranium could be economically exploited at present or in the future.

2. Definitions based on those published in OECD (2002), *Environmental Remediation of Uranium Production Facilities*, Paris.

Geologic types of uranium deposits[3]: uranium resources can be assigned on the basis of the following 15 major categories of uranium ore deposit types (arranged according to their approximate economic significance):

1. Sandstone deposits
2. Proterozoic unconformity deposits
3. Polymetallic Fe-oxide breccia complex deposits
4. Paleo-quartz-pebble conglomerate deposits
5. Granite-related
6. Metamorphite
7. Intrusive deposits
8. Volcanic-related deposits
9. Metasomatite deposits
10. Surficial deposits
11. Carbonate deposits
12. Collapse breccia-type deposits
13. Phosphate deposits
14. Lignite and coal
15. Black shale

Detailed descriptions with examples follow. Note that for Red Book reporting purposes only the major categories are used. However, descriptions of the sub-types for sandstone and Proterozoic unconformity deposits have also been included because of their importance.

1. Sandstone deposits: Sandstone-hosted uranium deposits occur in medium- to coarse-grained sandstones deposited in a continental fluvial or marginal marine sedimentary environment. Uranium is precipitated under reducing conditions caused by a variety of reducing agents within the sandstone, such as carbonaceous material, sulphides (pyrite), hydrocarbons and ferro-magnesian minerals (chlorite), bacterial activity, migrated fluids from underlying hydrocarbon reservoirs, and others. Sandstone uranium deposits can be divided into five main sub-types (with frequent transitional types between them):

   - Basal channel deposits: Paleodrainage systems consist of wide channels filled with thick, permeable alluvial-fluvial sediments. The uranium is predominantly associated with detrital plant debris in orebodies that display, in a plan view, an elongated lens or ribbon-like configuration and, in a section-view, a lenticular or, more rarely, a roll shape. Individual deposits can range from several hundred to 20 000 t of uranium, at grades ranging from 0.01% to 3%. Examples are the deposits of Dalmatovskoye (Transural Region), Malinovskoye (West Siberia), Khiagdinskoye (Vitim District) in the Russia, deposits of the Tono District (Japan), Blizzard (Canada) and Beverley (Australia).

   - Tabular deposits consist of uranium matrix impregnations that form irregularly shaped lenticular masses within reduced sediments. The mineralised zones are largely oriented parallel to the depositional trend. Individual deposits can contain several hundred tons up to 150 000 tons of uranium, at average grades ranging from 0.05% to 0.5%, occasionally up to 1%. Examples of deposits include Hamr-Stráz (Czech Republic), Akouta, Arlit, and Imouraren (Niger) and those of the Colorado Plateau (United States).

   - Roll-front deposits: The mineralised zones are convex in shape, oriented down the hydrologic gradient. They display diffuse boundaries with reduced sandstone on the down-gradient side and sharp contacts with oxidised sandstone on the up-gradient side. The mineralised zones are elongate and sinuous approximately parallel to the strike, and perpendicular to the direction of deposition and groundwater flow. Resources can range from a few hundred tons to several thousands of tons of uranium, at grades averaging 0.05% to 0.25%. Examples are Budenovskoye, Tortkuduk, Moynkum, Inkai and Mynkuduk (Kazakhstan); Crow Butte and Smith Ranch (United States) and Bukinay, Sugraly and Uchkuduk (Uzbekistan).

   - Tectonic/lithologic deposits are discordant to strata. They occur in permeable fault zones and adjacent sandstone beds in reducing environments created by hydrocarbons and/or detrital organic matter. Uranium is precipitated in fracture or fault zones related to

3. This classification of the geological types of uranium deposits was updated in 2011-2012 through a number of IAEA consultancies that included an update of the World Distribution of Uranium Deposits (UDEPO).

tectonic extension. Individual deposits contain a few hundred tons up to 5 000 tons of uranium at average grades ranging from 0.1-0.5%. Examples include the deposits of the Lodève District (France) and the Franceville basin (Gabon).

- Mafic dykes/sills in Proterozoic sandstones: mineralisation is associated with mafic dykes and sills that are interlayered with or crosscut Proterozoic sandstone formations. Deposits can be subvertical along the dyke's borders, sometime within the dykes, or stratabound within the sandstones along lithological contacts (Westmoreland District, Australia; Matoush, Canada). Deposits are small to medium (300-10 000 t) with grades low to medium (0.05-0.40%).

2. Proterozoic unconformity deposits: Unconformity-related deposits are associated with and occur immediately below and above an unconformable contact that separates Archean to Paleoproterozoic crystalline basement from overlying, redbed clastic sediments of Proterozoic age. In most cases, the basement rocks immediately below the unconformity are strongly hematised and clay altered, possibly as a result of paleoweathering and/or diagenetic/hydrothermal alteration. Deposits consist of pods, veins and semimassive replacements consisting of mainly pitchblende. They are preferentially located in two major districts, the Athabasca Basin (Canada) and the Pine Creek Orogen (Australia). The unconformity-related deposits include three sub-types:

    - Unconformity-contact deposits: Except for the low-grade Karku deposit (Russia), these all occur in the Athabasca Basin (Canada). Deposits develop at the base of the sedimentary cover directly above the unconformity. They form elongate pods to flattened linear orebodies typically characterised by a high-grade core surrounded by a lower grade halo. Most of the orebodies have root-like extensions into the basement. While some mineralisation is open space infill, much of it is replacement style. Often, mineralisation also extends up into the sandstone cover within breccias and fault zones forming "perched mineralisation". Deposits can be monometallic (McArthur River) or polymetallic (Cigar Lake). Deposits are medium to large to very large (1 000-200 000 t) and are characterised by their high grades (1-20%).

    - Basement-hosted deposits are strata-structure bound in metasediments below the unconformity on which the basinal clastic sediments rest. The basement ore typically occupies moderately to steeply dipping brittle shear, fracture and breccia zones hundreds of metres in strike length that can extend down-dip for several tens to more than 500 m into basement rocks below the unconformity. Disseminated and vein uraninite/pitchblende occupies fractures and breccia matrix but may also replace the host rock. High-grade ore is associated with brecciated graphitic schists. These deposits have small to very large resources (300-200 000 t), at medium grade (0.10-0.50%). Examples are Kintyre, Jabiluka and Ranger in Australia, Millennium and Eagle Point in the Athabasca Basin and Kiggavik and Andrew Lake in the Thelon Basin (Canada).

    - Stratiform structure-controlled deposits: low-grade (0.05-0.10%), stratabound, thin (1-5 m) zones of mineralisation are located along the unconformity between Archean, U-Th-rich granites and Proterozoic metasediments with minor enrichments along fractures. This type of deposit (Chitrial and Lambapur) has only been observed in the Cuddapah basin (India). Resources of individual deposits range between 1 000-8 000 t.

3. Polymetallic iron-oxide breccia complex deposits: This type of deposit has been attributed to a broad category of worldwide iron oxide-copper-gold deposits. Olympic Dam (Australia) is the only known representative of this type with significant by-product uranium resources. The deposit contains the world's largest uranium resources with more than 2 Mt of uranium. Deposits of this group occur in hematite-rich granite breccias and contain disseminated uranium in association with copper, gold, silver and rare earth elements. At Olympic Dam, this breccia is hosted within a Mesoproterozoic highly potassic granite intrusion that exhibits regional Fe-K-metasomatism. Significant deposits and prospects of this type occur in the same region, including Prominent Hill, Wirrda Well, Carrapeteena, Acropolis and Oak Dam as well as some younger breccia-hosted deposits in the Mount Painter area.

4. Paleo-quartz pebble conglomerate deposits: Deposits of this type contain detrital uranium oxide ores, which are found in quartz pebble conglomerates deposited as basal units in

fluvial to lacustrine braided stream systems older than 2 400-2 300 Ma. The conglomerate matrix is pyritic and contains gold, as well as other accessory and oxide and sulphide detrital minerals that are often present in minor amounts. Examples include deposits in the Witwatersrand basin, South Africa, where uranium is mined as a by-product of gold as well as deposits in the Blind River/Elliot Lake area of Canada.

5. Granite-related deposits include: i) true veins composed of ore and gangue minerals in granite or adjacent (meta-) sediments and ii) disseminated mineralisation in granite as episyenite bodies. Uranium mineralisation occurs within, at the contact or peripheral to the intrusion. In the Hercynian belt of Europe, these deposits are associated with large, peraluminous two-mica granite complexes (leucogranites). Resources range from small to large and grades are variable, from low to high.

6. Metamorphite deposits correspond to disseminations, impregnations, veins and shear zones within or affecting metamorphic rocks of various ages. These deposits are highly variable in sizes, resources and grades.

7. Intrusive deposits are contained in intrusive or anatectic igneous rocks of many different petrochemical compositions (granite, pegmatite, monzonite, peralkaline syenite and carbonatite). Examples include the Rossing and Rossing South (Husab) deposits (Namibia), the deposits in the Bancroft area (Canada), the uranium occurrences in the porphyry copper deposits of Bingham Canyon and Twin Butte (United States), the Kvanefjeld and Sorensen deposits (Greenland) and the Palabora carbonatite complex (South Africa).

8. Volcanic-related deposits are located within and near volcanic calderas filled by mafic to felsic, effusive and intrusive volcanic rocks and intercalated clastic sediments. Uranium mineralisation is largely controlled by structures as veins and stockworks with minor stratiform lodes. This mineralisation occurs at several stratigraphic levels of the volcanic and sedimentary units and may extend into the basement where it is found in fractured granite and metamorphic rocks. Uranium minerals (pitchblende, coffinite, U_6+ minerals, less commonly brannerite) are associated with Mo-bearing sulphides and pyrite. Other anomalous elements include As, Bi, Ag, Li, Pb, Sb, Sn and W. Associated gangue minerals comprise violet fluorite, carbonates, barite and quartz. The most significant deposits are located within the Streltsovska caldera in Russia. Other examples are known in China (Xiangshan District), Mongolia (Dornot and Gurvanbulag Districts), the United States (McDermitt caldera) and Mexico (Pena Blanca District).

9. Metasomatite deposits are confined to Precambrian shields in areas of tectono-magmatic activity affected by intense Na-metasomatism or K-metasomatism, which produced albitised or illitised facies along deeply rooted fault systems. In Ukraine, these deposits are developed within a variety of basement rocks, including granites, migmatites, gneisses and ferruginous quartzites, which produced albitites, aegirinites, alkali-amphibolic, as well as carbonate and ferruginous rocks. Principal uranium phases are uraninite, brannerite and other Ti-U-bearing minerals, coffinite and hexavalent uranium minerals. The reserves are usually medium to large. Examples include Michurinskoye, Vatutinskoye, Severinskoye, Zheltorechenskoye, Novokonstantinovskoye and Pervomayskoye deposits (Ukraine), deposits of the Elkon District (Russia), Espinharas and Lagoa Real (Brazil), Valhalla (Australia), Kurupung (Guyana), Coles Hill (US), Lianshanguan (China), Michelin (Canada) and small deposits of the Arjeplog region in the north of Sweden.

10. Surficial deposits are broadly defined as young (Tertiary to Recent), near-surface uranium concentrations in sediments and soils. The largest of the surficial uranium deposits are in calcrete (calcium and magnesium carbonates) found mainly in Australia (Yeelirrie deposit) and Namibia (Langer Heinrich deposit). These calcrete-hosted deposits mainly occur in valley-fill sediments along Tertiary drainage channels and in playa lake sediments in areas of deeply weathered, uranium-rich granites. Carnotite is the main uraniferous mineral. Surficial deposits also occur less commonly in peat bogs, karst caverns and soils.

11. Carbonate deposits are hosted in carbonate rocks (limestone, dolostone). Mineralisation can be syngenetic stratabound or more commonly structure-related within karsts, fractures, faults and folds. The only example of a stratabound carbonate deposits is the Tummalapalledeposit in India, which is hosted in phosphatic dolostone. At Mailuu-Suu, Kyrgyzstan and Todilto, United States. Another example includes deposits developed in solution collapse breccias occurring in limestone with intercalations of carbonaceous shale such as the Sanbaqi deposit, China.

12. Collapse breccia-type deposits occur in cylindrical, vertical pipes filled with down-dropped fragments developed from karstic dissolution cavities in underlying thick carbonate layers. The uranium is concentrated as primary uranium ore, mainly uraninite, in the permeable breccia matrix, and in the arcuate, ring-fracture zone surrounding the pipe. The pitchblende is intergrown with numerous sulphide and oxide minerals variably containing Cu, Fe, V, Zn, Pb, Ag, Mo, Ni, Co, As and Se. Type examples are the deposits in the Arizona Strip north of the Grand Canyon and those immediately south of the Grand Canyon in the United States. Resources are small to medium (300-2 500 t) with grades around 0.20-0.80%.

13. Phosphate deposits are principally represented by marine phosphorite of continental-shelf origin containing syn-sedimentary, stratiform, disseminated uranium in fine-grained apatite. Phosphorite deposits constitute large uranium resources (millions of tons), but at a very low grade (0.005-0.015%). Uranium can be recovered as a by-product of phosphate production. Examples include the Land Pebble District, Florida (land-pebble phosphate) (US), Gantour (Morocco) and Al-Abiad (Jordan). Another type of phosphorite deposits consists of organic phosphate, including argillaceous marine sediments enriched in fish remains that are uraniferous (Melovoye, Kazakhstan). Deposits in continental phosphates are not common.

14. Lignite-coal deposits consist of elevated uranium contents in lignite/coal mixed with mineral detritus (silt, clay), and in immediately adjacent carbonaceous mud and silt/sandstone beds. Pyrite and ash contents are high. Lignite-coal seams are often interbedded or overlain by felsic pyroclastic rocks. Examples are deposits of the south-western Williston basin, North and South Dakota (US), Koldjat and Nizhne Iliyskoe (Kazakhstan), Freital (Germany), Ambassador (Australia) and the Serres basin (Greece).

15. Black shale deposits include marine, organic-rich shale or coal-rich pyritic shale, containing synsedimentary, disseminated uranium adsorbed onto organic material, and fracture-controlled mineralisation within or adjacent to black shale horizons. Examples include the uraniferous alum shale in Sweden and Estonia, the Chattanooga shale (United States), the Chanziping deposit (China) and the Gera-Ronneburg deposit (Germany).

Appendix 4. List of abbreviations and acronyms

ARMZ	Atomredmetzoloto
CAREM	Central Argentina de Elementos Modulares
CCHEN	Chilean Nuclear Energy Commission
CGNPC	China General Nuclear Power Corporation
CEA	Commissariat à l’Energie Atomique et aux Energies Alternatives
CNEA	National Atomic Energy Commission (Argentina)
CNEN	National Nuclear Energy Commission (Brazil)
CNNC	China National Nuclear Corporation
CNPC	China National Petroleum Corporation
CNSC	Canadian Nuclear Safety Commission
COGEMA	Compagnie Générale des Matières Nucléaires
CRA	Conzinc Riotinto of Australia
DFS	Definitive feasibility study
DOE	Department of Energy (United States)
DU	Depleted uranium
EC	European Commission
EDF	Électricité de France
EIA	Environmental impact assessments
EPA	Environmental Protection Authority (United States)
EPL	Exclusive prospecting licence
EPR	European pressurised reactor
ENAMI	National Mining Company of Chile
ENUSA	Industrias Avanzadas, S.A. S.M.E. (Spain)
ERA	Energy Resources of Australia
ESA	Euratom Supply Agency
EU	European Union
Ga	Giga-years
GAC	Global Atomic Corporation
GDR	German Democratic Republic
GDRRE	Geological Division for Radioactive and Rare Elements
GWe	Gigawatt electric
ha	Hectare

HEU	Highly enriched uranium
HL	Heap leaching
IAEA	International Atomic Energy Agency
IBAMA	Brazilian Institute for the Environment and Renewable Natural Resources
INB	Industrias Núcleares do Brasil S.A
IPEN	Peruvian Institute Nuclear Energy
IPL	In-place leaching
IR	Inferred resources
ISL	In situ leaching
ISR	In situ recovery
IX	Ion exchange
JAEA	Japan Atomic Energy Agency
JAEC	Jordan Atomic Energy Commission
JOGMEC	Japan Oil, Gas and Metals National Corporation
JORC	Joint Ore Reserves Committee
JUMCO	Jordan Uranium Mining Company
KEPCO	Korea Electric Power Corporation
kg	Kilogram
km	Kilometre
lb	Pound
LEU	Low-enriched uranium
MOX	mixed oxide fuel
MRE	Mineral resource estimate
MTA	General Directorate of Mineral Research and Exploration (Türkiye)
MWe	Megawatt electric
NatU	Natural uranium
NEA	Nuclear Energy Agency
NMMC	Navoi Mining and Metallurgical Complex
NNSA	National Nuclear Security Administration (United States)
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission (United States)
NUA	Namibian Uranium Association
NWMO	Nuclear Waste Management Organization (Canada)
OECD	Organisation for Economic Co-operation and Development
OP	Open pit
ppm	Parts per million
PMCPA	Priargunsky Mining-Chemical Production Association
PR	Prognosticated resources

Pu	Plutonium
RAR	Reasonably assured resources
REE	Rare earth elements
RepU	Reprocessed uranium
RMRE	Reptile Mineral Resources & Exploration (Namibia)
SDAG	Sowjetisch-Deutsche Aktiengesellschaft
SMR	Small modular reactors
SR	Speculative resources
STUK	Radiation and Nuclear Safety Authority (Finland)
SWU	Separative work unit
SX	Solvent extraction
t	Tonnes (metric tons)
TAEK	Turkish Atomic Energy Authority
TENEX	Techsnabexport
Th	Thorium
tHM	Tonnes heavy metal
TOE	Tonnes oil equivalent
tU	Tonnes uranium
tU_3O_8	Tonnes triuranium octoxide
tUnat	Tonnes natural uranium equivalent
TVA	Tennessee Valley Authority
TVEL	TVEL Fuel Company
TVO	Teollisuuden Voima Oyj
TWh	Terawatt-hour
U	Uranium
UCIL	Uranium Corporation of India Limited
UDEPO	World Distribution of Uranium Deposits database (IAEA)
UEC	Uranium Energy Corporation
UG	Underground
USEC	United States Enrichment Corporation
USGS	US Geological Survey
US EIA	US Energy Information Administration
VostGOK	Vostochnyi Mining-process Combinat (Ukraine)
VVER	Water-water energetic reactor
WNA	World Nuclear Association

Appendix 5. Energy conversion factors

The need to establish a set of factors to convert quantities of uranium into common units of energy has become increasingly evident with the growing frequency of requests in recent years in relation to the various types of reactors.

Conversion factors and energy equivalence for fossil fuel for comparison

1 cal	=	4.1868 J
1 J	=	0.239 cal
1 tonne of oil equivalent (TOE) (net, lower heating value [LHV])	=	42 GJ * = 1 TOE
1 tonne of coal equivalent (TCE) (standard, LHV)	=	29.3 GJ* = 1 TCE
1 000 m^3 of natural gas (standard, LHV)	=	36 GJ
1 tonne of crude oil	=	approx. 7.3 barrels
1 tonne of liquid natural gas (LNG)	=	45 GJ
1 000 kWh (primary energy)	=	9.36 MJ
1 TOE	=	10 034 Mcal
1 TCE	=	7 000 Mcal
1 000 m^3 natural gas (atmospheric pressure)	=	8 600 Mcal
1 tonne LNG	=	11 000 Mcal
1 000 kWh (primary energy)	=	2 236 Mcal **
1 TCE	=	0.698 TOE
1 000 m^3 natural gas (atmospheric pressure)	=	0.857 TOE
1 tonne LNG	=	1.096 TOE
1 000 kWh (primary energy)	=	0.223 TOE
1 tonne of fuelwood	=	0.3215 TOE
1 tonne of uranium: light-water reactors	=	10 000-16 000 TOE
open cycle	=	14 000-23 000 TCE

* World Energy Council standard conversion factors (from WEC, 1998 Survey of Energy Resources, 18th Edition).

** With 1 000 kWh (final consumption) = 860 Mcal as WEC conversion factor.

Appendix 6. List of all Red Book editions (1965-2022) and national reports

Listing of Red Book editions (1965-2022)

OECD/ENEA*	World Uranium and Thorium Resources, Paris, 1965
OECD/ENEA	Uranium Resources, Revised Estimates, Paris, 1967
OECD/ENEA-IAEA	Uranium Production and Short-Term Demand, Paris, 1969
OECD/ENEA-IAEA	Uranium Resources, Production and Demand, Paris, 1970
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1973
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1976
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1977
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1979
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1982
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1983
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1986
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1988
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1990
OECD/NEA-IAEA	Uranium 1991: Resources, Production and Demand, Paris, 1992
OECD/NEA-IAEA	Uranium 1993: Resources, Production and Demand, Paris, 1994
OECD/NEA-IAEA	Uranium 1995: Resources, Production and Demand, Paris, 1996
OECD/NEA-IAEA	Uranium 1997: Resources, Production and Demand, Paris, 1998
OECD/NEA-IAEA	Uranium 1999: Resources, Production and Demand, Paris, 2000
OECD/NEA-IAEA	Uranium 2001: Resources, Production and Demand, Paris, 2002
OECD/NEA-IAEA	Uranium 2003: Resources, Production and Demand, Paris, 2004
OECD/NEA-IAEA	Uranium 2005: Resources, Production and Demand, Paris, 2006
OECD/NEA-IAEA	Uranium 2007: Resources, Production and Demand, Paris, 2008
OECD/NEA-IAEA	Uranium 2009: Resources, Production and Demand, Paris, 2010
OECD/NEA-IAEA	Uranium 2011: Resources, Production and Demand, Paris, 2012
OECD/NEA-IAEA	Uranium 2014: Resources, Production and Demand, Paris, 2014
OECD/NEA-IAEA	Uranium 2016: Resources, Production and Demand, Paris, 2016
OECD/NEA-IAEA	Uranium 2018: Resources, Production and Demand, Paris, 2018
OECD/NEA-IAEA	Uranium 2020: Resources, Production and Demand, Paris, 2020
OECD/NEA-IAEA	Uranium 2022: Resources, Production and Demand, Paris, 2023

* ENEA: European Nuclear Energy Agency; former name of the Nuclear Energy Agency (NEA).

Index of national reports in Red Books

(The following index lists all national reports by the year in which these reports were published in the Red Books)

	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Algeria						1976	1977	1979	1982					
Argentina		1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Armenia														
Australia		1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Austria							1977							
Bangladesh											1986	1988		
Belgium									1982	1983	1986	1988	1990	1992
Benin													1990	
Bolivia							1977	1979	1982	1983	1986			
Bophuthatswana †									1982					
Botswana								1979		1983	1986	1988		
Brazil				1970	1973	1976	1977	1979	1982	1983	1986			1992
Bulgaria													1990	1992
Cameroon							1977		1982	1983				
Canada	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Central African Republic				1970	1973		1977	1979			1986			
Chad														
Chile							1977	1979	1982	1983	1986	1988		1992
China													1990	1992
Colombia							1977	1979	1982	1983	1986	1988	1990	
Congo		1967												
Costa Rica									1982	1983	1986	1988	1990	
Côte d'Ivoire									1982					
Cuba												1988		1992
Czech Republic														
Czech and Slovak Rep.													1990	
Denmark (Greenland)	1965	1967		1970	1973	1976	1977	1979	1982	1983	1986		1990	1992
Dominican Republic									1982					
Ecuador							1977		1982	1983	1986	1988		
Egypt							1977	1979			1986	1988	1990	1992
El Salvador										1983	1986			
Estonia														
Ethiopia								1979		1983	1986			
Finland					1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
France	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Gabon		1967		1970	1973				1982	1983	1986			
Germany				1970		1976	1977	1979	1982	1983	1986	1988	1990	1992

† Bophuthatswana is a former republic, dissolved in 1994, in the north-western region of South Africa.

Index of national reports in Red Books (*cont'd*)

1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	
				2002	2004	2006	2008		2012	2014	2016	2018	2020	2022	Algeria
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Argentina
			2000	2002	2004	2006		2010	2012	2014	2016	2018	2020	2022	Armenia
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Australia
															Austria
														2022	Bangladesh
1994	1996	1998	2000	2002	2004	2006	2008								Belgium
															Benin
												2018		2022	Bolivia
															Bophuthatswana
								2010	2012	2014	2016		2020	2022	Botswana
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Brazil
1994	1996	1998					2008	2010						2022	Bulgaria
															Cameroon
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Canada
														2022	Central African Republic
										2014	2016				Chad
1994	1996	1998	2000	2002	2004	2006	2008		2012	2014	2016	2018	2020	2022	Chile
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	China
	1996	1998					2008								Colombia
															Congo
															Costa Rica
															Côte d'Ivoire
	1996	1998													Cuba
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Czech Republic
															Czech and Slovak Rep.
	1996	1998			2004			2010	2012	2014	2016	2018	2020	2022	Denmark (Greenland)
															Dominican Republic
														2022	Ecuador
1994	1996	1998	2000		2004	2006	2008	2010					2020	2022	Egypt
															El Salvador
		1998			2004										Estonia
									2012						Ethiopia
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Finland
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	France
	1996	1998	2000	2002	2004	2006									Gabon
1994	1996	1998	2000	2002		2006	2008	2010	2012	2014	2016	2018	2020	2022	Germany

Index of national reports in Red Books *(cont'd)*

	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Ghana							1977			1983				
Greece							1977	1979	1982	1983	1986	1988	1990	1992
Guatemala											1986	1988		
Guyana								1979	1982	1983	1986			
Hungary														1992
India	1965	1967		1970	1973	1976	1977	1979	1982	1983	1986		1990	1992
Indonesia							1977				1986	1988	1990	1992
Iran, Islamic Republic of							1977							
Iraq														
Ireland								1979	1982	1983	1986			1992
Italy		1967		1970	1973	1976	1977	1979	1982	1983	1986	1988		1992
Jamaica									1982	1983				
Japan	1965	1967		1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Jordan							1977				1986	1988	1990	1992
Kazakhstan														
Korea						1976	1977	1979	1982	1983	1986	1988	1990	1992
Kyrgyzstan														
Lesotho												1988		
Liberia							1977			1983				
Libyan Arab Jamahiriya‡										1983				
Lithuania														
Madagascar						1976	1977	1979	1982	1983	1986	1988		
Malawi														
Malaysia										1983	1986	1988	1990	1992
Mali											1986	1988		
Mauritania													1990	
Mexico				1970	1973	1976	1977	1979	1982		1986		1990	1992
Mongolia														
Morocco	1965	1967				1976	1977	1979	1982	1983	1986	1988	1990	
Namibia								1979	1982	1983	1986	1988	1990	
Nepal														
Netherlands									1982	1983	1986		1990	1992
New Zealand		1967					1977	1979						
Niger		1967		1970	1973		1977				1986	1988	1990	1992
Nigeria								1979						
Norway								1979	1982	1983				1992
Pakistan		1967												
Panama										1983		1988		
Paraguay										1983	1986			
Peru							1977	1979		1983	1986	1988	1990	1992
Philippines							1977		1982	1983	1986		1990	
Poland														

‡ Libya as of 2011.

Index of national reports in Red Books *(cont'd)*

1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	
															Ghana
1994	1996	1998													Greece
															Guatemala
														2022	Guyana
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Hungary
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	India
1994	1996	1998	2000	2002	2004	2006		2010	2012	2014	2016	2018	2020	2022	Indonesia
		1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Iran, Islamic Republic of
											2016				Iraq
		1998													Ireland
1994	1996	1998	2000						2012	2014	2016				Italy
															Jamaica
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018		2022	Japan
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Jordan
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Kazakhstan
1994	1996	1998	2000	2002	2004	2006	2008	2010							Korea
	1996			2002											Kyrgyzstan
															Lesotho
															Liberia
															Libyan Arab Jamahiriya
1994	1996	1998	2000	2002	2004	2006	2008								Lithuania
													2020		Madagascar
			2000				2008	2010	2012	2014	2016		2020	2022	Malawi
1994	1996	1998	2000	2002											Malaysia
										2014	2016	2018	2020	2022	Mali
											2016		2020	2022	Mauritania
1994	1996	1998	2000						2012		2016	2018	2020	2022	Mexico
1994	1996	1998						2010	2012	2014	2016	2018	2020	2022	Mongolia
		1998													Morocco
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Namibia
														2022	Nepal
1994	1996	1998	2000	2002											Netherlands
															New Zealand
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Niger
															Nigeria
	1996	1998													Norway
1994		1998	2000												Pakistan
															Panama
												2018		2022	Paraguay
1994	1996	1998	2000		2004	2006	2008	2010	2012	2014	2016	2018		2022	Peru
1994	1996	1998	2000	2002	2004	2006									Philippines
			2000	2002			2008	2010	2012	2014	2016			2022	Poland

Index of national reports in Red Books *(cont'd)*

	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Portugal	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Romania														1992
Russia														
Rwanda											1986			
Saudi Arabia														
Senegal									1982					
Slovak Republic														
Slovenia														
Somalia							1977	1979						
South Africa	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986			1992
Spain	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Sri Lanka							1977		1982	1983	1986	1988		
Sudan							1977							
Surinam									1982	1983				
Sweden	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Switzerland						1976	1977	1979	1982	1983	1986	1988	1990	1992
Syrian Arab Republic									1982	1983	1986	1988	1990	
Tajikistan														
Tanzania													1990	
Thailand							1977	1979	1982	1983	1986	1988	1990	1992
Togo								1979						
Türkiye					1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Turkmenistan														
Ukraine														
United Kingdom						1976	1977	1979	1982	1983	1986	1988	1990	1992
United States	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Uruguay							1977		1982	1983	1986	1988	1990	
USSR (former)														1992
Uzbekistan														
Venezuela											1986	1988		
Viet Nam														1992
Yugoslavia					1973	1976	1977		1982				1990	1992
Zaire [§]					1973		1977					1988		
Zambia											1986	1988	1990	1992
Zimbabwe									1982			1988		1992

§ Zaire is the former name – between 1971 and 1997 – of the Democratic Republic of the Congo.

Index of national reports in Red Books *(cont'd)*

1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016		2020	2022	Portugal
1994	1996	1998	2000	2002											Romania
1994		1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Russia
															Rwanda
														2022	Saudi Arabia
												2018	2020	2022	Senegal
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016			2022	Slovak Republic
1994	1996	1998		2002	2004	2006	2008	2010		2014	2016	2018	2020	2022	Slovenia
															Somalia
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016		2020	2022	South Africa
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Spain
													2020		Sri Lanka
															Sudan
															Surinam
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016		2020		Sweden
1994	1996	1998	2000	2002	2004	2006	2008								Switzerland
1994															Syrian Arab Republic
				2002											Tajikistan
								2010	2012	2014	2016	2018	2020	2022	Tanzania
1994	1996	1998	2000	2002		2006				2014	2016	2018	2020		Thailand
															Togo
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Türkiye
					2004										Turkmenistan
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	Ukraine
1994	1996	1998	2000	2002	2004	2006	2008	2010		2014	2016	2018			United Kingdom
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	United States
															Uruguay
															USSR (former)
1994	1996	1998	2000	2002	2004	2006			2012		2016	2018	2020	2022	Uzbekistan
															Venezuela
1994	1996	1998	2000	2002	2004	2006	2008			2014	2016	2018	2020	2022	Viet Nam
															Yugoslavia
															Zaire
1994	1996	1998							2012	2014	2016	2018	2020	2022	Zambia
1994	1996	1998													Zimbabwe

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Uranium 2022: Resources, Production and Demand

Uranium is the main raw material fuelling all nuclear fission reactors today. Countries around the world use it to reliably generate low-carbon electricity, process heat and hydrogen as part of their plans to reduce carbon emissions and increase energy security and supply. There is no nuclear fission power possible – of whatever kind – without uranium.

This 29th edition of the "Red Book", a recognised world reference on uranium jointly prepared by the Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), provides analyses and information from 54 uranium producing and consuming countries. The present edition reviews world uranium market fundamentals and presents data on global uranium exploration, resources, production and reactor-related requirements. It offers updated information on established uranium production centres and mine development plans, as well as projections of nuclear generating capacity and reactor-related requirements through 2040.

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