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Strengthening the ROK-US Nuclear Partnership

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EXECUTIVE SUMMARY

Over the last forty years, South Korea (hereafter ROK or Korea) and the United States have become essential partners on nuclear matters. The United States provided the technology and knowhow necessary for Korea to establish a nuclear sector. Koreans mastered that technology and have worked to improve on it, with the twin goals of expanding their country's energy independence and becoming a leading exporter of nuclear power production facilities. The two states' nuclear energy industries have become intertwined. They cooperate on multiple initiatives to strengthen international nuclear security and nonproliferation measures. Collaborative research ties amongst nuclear scientists from both countries run deep. Arguably, each state is the other's most important nuclear partner.

As with all maturing relationships, there remain differences of view and priority that must be managed. Though unlikely, a disruption in ROK-US nuclear relations would have wide-ranging, deleterious effects on both states. For this reason, the conclusion in June 2015 of a new bilateral treaty, the Agreement for Cooperation Between the Government of the United States of America and the Government of the Republic of Korea Concerning Peaceful Uses of Nuclear Energy (hereafter referred to as the 123 agreement after section 123 of the Atomic Energy Act, the relevant US statute) is a critical milestone. The new agreement establishes the terms for nuclear cooperation for the next twenty years. It is expansive and forward-looking, providing the basis for unusually broad and deep nuclear ties. The 123 agreement will bring predictability to the relationship at a time when the global nuclear energy outlook remains in flux.

However, the new nuclear agreement only managed to partially resolve several deep-seated differences between the two sides that were illustrated by the fact that negotiations on a new agreement lasted more than four years and required an extension to complete. The agreement creates a new political framework for managing divergent views over how to cooperate most effectively, but differences may yet re-emerge and frustrate cooperation. The challenge before the two governments now is to implement the new agreement in ways that can either resolve or remove these differences and solidify existing ties. In other words, the two countries should seek to build a nuclear partnership in deed, not just in word.

This report articulates a vision for ROK-US nuclear partnership for the next two decades, a period which aligns with the duration of the new agreement for cooperation. It highlights challenges and opportunities and provides recommendations intended to deepen and expand the range of existing cooperation in ways that will support a stable and sustainable nuclear partnership. The objective of the report is to describe a desirable and stable end-state for the relationship—an enduring partnership—and to identify steps along the path to achieve it. It discusses multiple areas of cooperation, assesses strengths and weaknesses of existing ties, and identifies practical activities both parties can pursue toward building the partnership.

Why a Nuclear Partnership?

Civil nuclear cooperation agreements establish the legal terms and procedures for trade and cooperation. They define the parameters of a nuclear relationship—the permissible content—without mandating actions to be taken. Often these agreements merely facilitate commercial interactions, but some create a broad basis for joint work by the governments and their specialized nuclear institutes and agencies. The 2015 ROK-US agreement is remarkable because it provides a comprehensive foundation for nuclear collaboration, perhaps the most specifically expansive such agreement that exists for either of the two countries. It reflects the deep political ties between the two states, the advanced state of their respective nuclear enterprises, and the potential for further cooperation.

The achievement of a broader partnership should help mitigate political differences while creating positive multiplier effects, whether in trade, research and development, or governance. The two states will be stronger if they work together internationally than if they work independently from each other. The new 123 agreement explicitly references the desire of both states in this regard to expand existing cooperation to achieve "an enduring strategic nuclear energy partnership."

A strong basis for partnership already exists. Political elites and nuclear scientists in both states share similar views about the role of nuclear energy nationally and globally. They also share the objectives of maintaining sustainable nuclear power for low-carbon energy, developing next generation reactor designs, and advancing nuclear science. Both states strive to facilitate the safe operation of nuclear reactors and maintain public confidence in nuclear power. They support improving practices for nuclear security and strengthening the global nuclear security architecture. And they share concerns about regional proliferation and the health of the global nonproliferation regime. There is also a complementarity in nuclear trade between the states, despite competition between Korean and US firms in some markets. And, of course, partnership is undergirded by the sixty-year old political, security, and economic alliance that endures between Seoul and Washington.

A nuclear partnership allows both states to further develop their own industries, advance the state of the field, strengthen safety, promote effective governance, maintain effective regulatory oversight for the sector, and address shared issues (e.g., decommissioning), while setting standards and contributing to global nuclear energy development in a manner that contributes to strengthening of best practices for safety, security, and safeguards. A more expansive and equal nuclear partnership clearly serves the interests of both countries.

Achieving the Vision of a Nuclear Partnership: Recommendations

Seizing this opportunity will be challenging: to maintain focus on the longer-term interest while dampening short-term political differences and overcoming bureaucratic tendencies; to retain the interagency consensus built during the negotiations; to take decisive steps to move forward on opportunities for mutually-beneficial work; and to expand on the existing foundation with concrete steps to create the durable basis for partnership. Understandably, both states face budgetary challenges that make a large expansion of cooperation unlikely in the near term. In the meantime, to gather steam, existing programs can be augmented or refocused on activities that can help build the partnership.

To continue to build this partnership, Seoul and Washington can take concrete steps in the following areas:

- *Building Interagency Cooperation and Expertise*. The new High-Level Bilateral Commission (HLBC) established by the 123 agreement creates the potential for enhanced technical and political coordination of civil nuclear relations between the two countries. Initially the commission will have four working groups on spent fuel management, trade cooperation, assured fuel supply, and nuclear security, topics that are already fixtures of bilateral nuclear dialogue. Thus, to be most effective as an instrument for enhancing the nuclear partnership, the two sides should develop joint road maps for the full range of nuclear cooperation beyond these four topics. Realizing the potential inherent in the commission also will require additional expertise in both countries, particularly on the Korean side. Korea should launch a major effort to develop a career track for technical experts in the government, who could provide dedicated technical and legal policy expertise to a range of ministries with nuclear responsibility in Korea. Developing such expertise would contribute to a more effective Korean interagency process spanning the range of civil nuclear issues.

  The United States can support these efforts through educational exchanges, training, and swaps of relevant government personnel; public diplomacy outreach; and civil society cooperation. In addition, the US.government should seek to broaden the number of nuclear experts in relevant agencies with on-the-ground experience in Korea and Korean language skills. Several universities and nuclear laboratories in the United States in the last decade have launched focused, cross-discipline training programs on bridging gaps between policy and technology, while pilot efforts are also underway at several institutions in Korea. These efforts should be coordinated and expanded to address legal and regulatory issues, strategies for spent fuel management, decommissioning, international safety, security, and nonproliferation regimes, and so forth.

- *Enhancing Nuclear Safety*. The new 123 agreement offers an opportunity to build on the fruitful technical cooperation the US Nuclear Regulatory Commission (NRC) has long enjoyed with the Korean Institute of Nuclear Safety (KINS), a technical body. However, broader policy cooperation between the NRC and the Korean Nuclear Safety and Security Commission (KNSSC), a new policy-making institution to which KINS reports, has not yet reached a mutually satisfactory level. Korea must take steps to build greater technical and legal policy expertise at the newly formed commission.

It also needs to implement a legal framework which provides greater independence for the regulator, as well as to promote a government and national safety culture that support such independence. Close cooperation with the NRC could help accomplish these steps and, by visibly taking steps to encourage outside review and enhance public engagement, raise confidence in nuclear safety. Furthermore, Korean regulators should engage in more outreach to both domestic and international nongovernmental organizations to promote support and accountability.

In addition to their bilateral cooperation, the two countries should continue to support the leadership demonstrated by Korea to improve nuclear safety in Northeast Asia and extend such cooperation to other regions. The United States should send technical experts to participate in regional meetings on nuclear safety in Northeast Asia, a region which has some 60 nucler power reactors operating today with the potential of 75 more to come online in the next decade. Drawing on experience gained in the United Arab Emirates, where a Korean-led consortium (that includes US-based Westinghouse) is building four nuclear reactors, the two countries should consider establishing a joint program for nuclear safety outreach and education in the Middle East, given both countries' political and nuclear commercial interests in the region.

- *Developing a Decommissioning Industry*. Decomissioning nuclear facilities that have reached the end of their lifespans is a major future challenge for which ground should be laid now, particularly given the public-private partnership opportunities that will exist to address the coming wave of facility retirements in the next decades. Recent efforts in Korea to establish a decommissioning industry are an important signal of this potential. However, ensuring that large facilities can be decontaminated and dismantled in a safe and secure manner and in ways that retain public confidence will require carefully coordinated regulatory policy approaches involving government, utilities, and private industry. The United States has gained some experience with this challenge; together, both states have a chance to develop and share best technical and regulatory approaches.

- *Assuring South Korea's nuclear fuel cycle*. Though the new agreement does not fully meet South Korea's goal of obtaining advance US consent for uranium enrichment or reprocessing of spent nuclear fuel, it does not preclude this possibility in the future. An important milestone will occur in 2021, with the conclusion of a joint, ten-year-long technical, economic, and nonproliferation feasibility study. Achieving a successful conclusion of this study will be difficult, given the technical challenges involved and differing perceptions of the yardsticks in some areas such as economic feasibility. In the meantime, the two countries should take advantage of the next six years to advance initiatives designed to meet Korea's goals of assuring a supply of enriched uranium product for reactor fuel and enhancing the long-term management of Korea's spent fuel.

The most urgent challenge faced by the Korean nuclear industry is finding a suitable place to store its spent nuclear fuel once existing and planned spent fuel pools begin reaching capacity during the 2020s. In this regard, it is clear that dry cask interim storage will be needed to handle the older spent fuel, most likely at existing reactor sites. The United States can provide South Korea with useful expertise in both the technical and public relations aspects of this move. Finally, though a decision on whether and how to proceed with work specifically on pyroprocessing awaits the conclusion of the joint feasibility study, the two sides should explore other back-end technologies including geological repositories and deep boreholes. Both states face significant public policy challenges regarding spent fuel management and can gain from technical research and policy cooperation to develop sound approaches.

- *Supporting US and ROK nuclear exports*. In some ways, the US and Korean nuclear industries are natural partners given their longstanding and deep cooperation and their complementary strengths, back by shared geopolitical views and alliance relations at the state level. Moreover, both counties' potential nuclear exports are threatened by aggressive sales practices from Russia and an emerging challenge from China. To be sure, however, the unusual nature of the nuclear industry, with its mixture of cooperation and competition and differing levels of government involvement in the two countries present structural challenges to building on the trade facilitation aspects of the 123 agreement. To compete more effectively, both together or separately, Seoul and Washington should take steps to improve their own export capabilities. Korea needs to improve its ability to finance exports and build third-country export control capacity and Washington needs to streamline its export approval process. An extension of the master agreement between the Korea Electric Power Corporation (KEPCO) and Westinghouse could also play an important role in fostering cooperation in the most important arena: that of the private sector.

- *Bolstering Nuclear Security and Nonproliferation*. Korea's hosting of the 2012 Nuclear Security Summit (NSS) appeared to be a watershed moment in which Korea gained experience that would allow it to play a greater leadership role in global nuclear governance. The United States greatly values Korea's efforts to take on more global responsibility in this area. However, notwithstanding major coordination through the NSS process, it is not clear that Korea has an overarching vision for how it can continue to lead and contribute on this issue, particularly after the NSS process ends in 2016. Areas in which Korea, supported by the United States, should consider playing an enduring role include minimizing the use of highly enriched uranium (HEU), radiological source tracking, and the substitution of high-risk alternatives for high-risk radiological sources. Regionally, the ROK could devote particular attention to

Southeast Asia and the Middle East. In addition, Seoul should move forward on efforts to better coordinate the work of "Centers of Excellence" in nuclear security in China, Japan, and South Korea, and seek to have these centers play more of a role in the nuclear security policy making process after the NSS process runs its course.

On most nonproliferation matters, Korea and the United States are already firm partners, working together both bilaterally and through multilateral institutions. One area in which they might extend this cooperation is through more coordinated nonproliferation outreach and training. For example, it would be useful, particularly for so-called "nuclear newcomer" states initiating nuclear power programs, to develop a comprehensive model law that rationalizes the myriad responsibilities mandated by international legal and policy instruments. Separately, building on longstanding work done at the track-two level, Washington and Seoul should enhance bilateral efforts to prepare coordinated approaches to address the multiple technical, legal, and policy issues that derive from various possible resolutions of the North Korea nuclear issue. Given the number of government entities that will be involved, such coordination should be a priority so as not to miss opportunities, or inadvertently make problems worse through misunderstanding or poor division of labor.

- *Furthering Nuclear Science, Research and Development*. Given the maturity and breadth of the nuclear energy infrastructure and communities in the two countries, several opportunities exist to further bilateral cooperation in addition to cooperation through multinational fora such as the Generation IV International Forum, the International Project on Innovative Nuclear Reactors and Fuel Cycle, and the International Framework for Nuclear Energy Cooperation. These areas include research and development on advanced nuclear reactors such as fast and small modular reactors, extending the lifetimes of reactors, new fuel types—particularly those with greater accident tolerance and higher assays of low enriched uranium—and various efforts to address spent fuel including storage techologies and deep borehole disposal.

The Evolution of ROK-US Nuclear Cooperation: 1973-2015

Since the 1970s, ROK-US nuclear cooperation has been central to Korea's emergence as one of the most vibrant nuclear energy markets today.[1] The breadth and depth of cooperation increased steadily, as Korea transformed from recipient and consumer of foreign nuclear technology to developer, manufacturer, and now exporter of modern nuclear power stations. Korea and the United States conduct substantial nuclear trade with each other, in excess of $350 million over the last decade. Korean and American firms are also cooperating in the construction of nuclear power reactors in the United Arab Emirates. And Korean and American nuclear scientists are collaborating on several projects investigating advanced spent fuel management technologies.

Though nuclear industry in the United States has undergone a period of stasis in recent decades, as it has globally following the 2011 Fukushima accident in Japan, in Korea it remains poised to become a pillar of its export and manufacturing economy along with electronics, automobiles, and steel. Commensurate with Korea's status as one of the top five global producers of nuclear electricity, Korea has emerged as a leader in advanced nuclear research and development and nuclear security. It is a key contributor to global efforts to strengthen nuclear governance and sustain multilateral cooperation in next-generation nuclear science.

The historically strong linkages between US and Korean nuclear programs and policies have created interdependencies and tensions that have been central to the negotiation of the new, modern agreement for nuclear cooperation between the two: the 2015 123 agreement. This negotiation grew increasingly political and contentious over the last four years, with the two states taking divergent positions especially on questions relating to Korean development of fuel cycle capabilities—uranium enrichment to fuel reactors and reprocessing (or recycling) of spent fuel to reduce nuclear waste volumes. Disagreement on these provisions seemed to threaten an otherwise broad consensus between nuclear communities in both states for which continued partnership is clearly to their mutual benefit.

The discord produced by the negotiations should merely be a blip in an otherwise strong record of collaboration. Indeed, there is little if any dissent in the United States about the desirability of Korea attaining the three objectives for cooperation identified by President Park Geun-Hye: security of uranium supplies; near-term resolution of the spent fuel challenge; and enhanced competitiveness for Korean nuclear industry. Explicit focus on cooperative activities to fulfill these objectives, among others, should help restore the consensus among both technical and policy communities on the bilateral nuclear relationship.

[1] The previous ROK-US nuclear cooperation entered into force in 1973 and originally was to last thirty

The Establishment of a New Framework for Nuclear Cooperation

The ROK-US Nuclear Cooperation Agreement defines the scope and process for managing effective nuclear cooperation between the United States and the Republic of Korea. The new agreement replaces a predecessor agreement that was negotiated when South Korea's nuclear program was nascent and largely dependent on the United States for infrastructure and knowhow. The new agreement envisions cooperation between mature partners that share common challenges and opportunities related to the safe and efficient operation of nuclear plants and the need to ensure that proper safeguards are in place to prevent nuclear proliferation. It outlines the parameters and limits of effective nuclear cooperation based on a continuing commitment to peaceful, responsible, and safe development of nuclear power.

The new agreement necessarily is shaped by the main interests of both sides, including US concerns about safeguards and nonproliferation and South Korean concerns regarding fuel supply, spent fuel management, and cooperation on nuclear power plant exports. Recognizing the political sensitivities and importance of effective joint management of these issues, the agreement establishes a new high-level consultation process for managing the relationship. The High-Level Bilateral Commission will be headed by the ROK vice minister for foreign affairs and the US deputy secretary of energy. It augments the pre-existing working-level Joint Standing Committee on Nuclear Energy Cooperation, which focuses more on technical issues and is not a venue capable of addressing major political differences. The commission can serve a most useful feature in breaking down bureaucratic stovepipes and effectively coordinating among competing interests on each side, a prerequisite to realizing the vision of a broad partnership.

The agreement affirmed Korea's inalienable right to peaceful uses of nuclear technology, as well as the desire of the parties to enter into new arrangements "without prejudice to the sovereignty of each party." It also establishes mechanisms for addressing areas where the United States and Korea may have differences in view, in particular a dialogue process to address areas of disagreement as South Korea's industry continues to mature and as circumstances warrant. The agreement handled the most sensitive issues in the following fashion:

Enrichment - The agreement stipulates that uranium enrichment is permitted, but subject to agreement in writing. This promise of future consideration was sufficient to satisfy Korea's request that its right to conduct enrichment be acknowledged. To reduce the probability that Korea might find reason to pursue enrichment in the future, the United States agreed to an unusual provision, to "take such actions as may be necessary and feasible to ensure a reliable supply" of uranium for nuclear reactor fuel.

Spent Fuel Management – Korea seeks to utilize pyroprocessing technology, which is a form or reprocessing, as part of its spent fuel management strategy. Like enrichment, the agreement permits reprocessing as part of joint research on spent fuel management, again subject to subsequent written agreement following consultations. In many respects, Korea had already agreed to delay this issue by entering into a ten-year Joint Fuel Cycle Study with the United States, under which it granted the United States consent rights over where, how and when the joint technology might be used in Korea in the future. Only at the end of that study will the two sides discuss whether pyroprocessing is technically feasible, economically viable, effectively safeguardable, and will not increase proliferation risks. In the interim, the agreement permits Korea to conduct an early stage of pyroprocessing to reduce waste volume provided that the technology employed is not capable of separating material that can be used in nuclear weapons. The agreement allows joint experimentation involving forms of reprocessing to take place at specified facilities in the United States and South Korea and is linked to ROK-US research cooperation on next generation nuclear energy systems. It also permits Korea to conduct post-irradiation experiments on nuclear fuel. Finally, the agreement permits transfers to Korea of other special nuclear material for experiments related to the operation of fast reactors, another area of cooperation between the two states' nuclear laboratories linked to Korea's spent fuel management strategy.

Trade facilitation – Bilateral nuclear trade between the United States in Korea has increased significantly. Two-way trade over the decade ending in 2013 totaled over $360 million. And between 2009 and 2013, the United States imported $140 million in nuclear commodities from Korea, and exported $131 million in return.[2] Korea's winning $20 billion bid to construct four nuclear power reactors in the United Arab Emirates marked a major milestone in its evolution from consumer to exporter of nuclear technology, but Korea's win also benefits the US nuclear industry, which provides critical components for the reactors Korea is constructing.

Korea is actively bidding to build nuclear research and power reactors in several other countries. The 123 agreement stipulates that neither party will use export control measures or technology licensing processes to gain commercial advantage, and that they will pre-authorize transfers of equipment and material to states with whom both have nuclear cooperation agreements. The parties agree to consult and reach prior agreement in advance of any revision to the list of countries to which this provision applies. This will facilitate, simplify, and expedite licensing for major nuclear construction projects involving both states in the future.

[2] US data reported to the United Nations Commodity Trade Statistics Database, Department of Economic and Social Affairs/Statistics Division.

The Post-Agreement Agenda

The 123 agreement not only addresses the three priority areas noted above, but also authorizes cooperation in a number of other areas. It identifies the following eight topics:

- nuclear safety including regulatory and operational aspects of radiological protection;
- next generation nuclear energy systems including advanced nuclear fuel cycle technology;
- radioactive waste management including disposal;
- production of radioactive isotopes and application of radiation and radioactive isotopes;
- safeguards and physical protection;
- controlled thermonuclear fusion including in multilateral projects;
- design and manufacture of nuclear fuels;
- development, design, construction, operation, maintenance and use of reactors, reactor experiments, and decommissioning.

It is apparent from this list that both states share considerable interests and face their own domestic challenges in a number of these areas. For example, both have aging nuclear fleets and are now in the process of deciding whether and how to relicense these reactors, for how long, and under what conditions. The United States has more immediate experience than Korea in this regard, but over the next decade, both will face relicensing decisions on reactors of designs deployed in both countries. Thus, there is considerable opportunity to share analyses and regulatory best practices.

The same considerations apply to reactors and other nuclear facilities that have reached the end of their operational lives and face decommission. These numbers will increase in the decades ahead, and new industries (with standards, regulations, and best practices) will need to grow to meet this demand. There is substantial incentive for both states to get a head start on this challenge, which will provide additional opportunities for enhanced government-industry collaboration.

Though both states have vibrant science and technology industries, they both need to maintain a nuclear workforce with the technical, policy, and legal skills required to address many of the topics on this list. In the United States, several training programs put in place over the last decade have begun to address this issue, and there are nascent programs in Korea. Technical and policy exchanges provide another obvious opportunity to build long-lasting ties between the US and ROK nuclear communities.

Finally, with the decision by Korea to host the 2012 Nuclear Security Summit, Seoul demonstrated its growing interest in questions of international nuclear governance. In 2016, Korea will chair the Nuclear Suppliers Group and convene the annual plenary meeting in Seoul. The pattern of cooperation between the United States and Korea established by Seoul's leadership is a clear positive. The two states will have numerous opportunities to join forces in advancing efforts in various multilateral regimes.

The negotiation of the 123 agreement has come to be seen as a foreign policy success in both Seoul and Washington. In Korea, this success is partly because the agreement substantively addressed many of Korea's concerns, but also because of the careful spadework undertaken by senior ROK officials to shape political perceptions of the agreement. In particular, Ministry of Foreign Affairs officials were able to counter arguments prevalent among some Korean media that the agreement would compromise Korea's peaceful nuclear sovereignty by forfeiting its rights to carry out fuel cycle activities. In this regard, and in light of past foreign policy controversies over the Korea-US free trade agreement and beef imports, for example, a major goal of both governments was to mitigate any political backlash in Korea, despite the lack of a clear, long-term resolution of some key issues such as pyroprocessing consent. Sustaining this success is not a foregone conclusion, however, and will require continued investment in both the concept and actual facts of a nuclear partnership moving forward.

Building Interagency Cooperation and Expertise

Joint ROK-US efforts to establish a nuclear partnership require regular, high-level political coordination to ensure that agreed tasks are being implemented appropriately and that potential disgreements can be addressed before they fester. This job will fall to the HLBC, the new body charged with managing both the foreign policy and technical aspects of sustained cooperation. Though the commission has an important mandate, there is not yet a shared vision for how it should operate. The question before both governments is how to operationalize and staff the HLBC in ways that will sustain momentum, maximize its utility, and facilitate a partnership in line with both foreign policy and technical objectives identified in the 123 agreement.

Thus far, the two sides have agreed that the commission will oversee four working groups: spent fuel management, promotion of nuclear exports and export control cooperation, assured fuel supply, and nuclear security. For these areas, and others, the parties should develop road maps with clear objectives and milestones, particularly when they involve equities of multiple agencies. To the extent possible, both sides should work out equitable joint-funding of agreed areas for cooperation, in order to sustain the involvement of relevant government agencies and create a shared stake in the outcomes.

It is somewhat surprising given the scope of existing cooperation, the breadth of the new 123 agreement, and the prominence it is given in other bilateral relationships (most notably between Japan and the United States) that emergency planning and response are not among the issues identied in the 123 or for discussion in the HLBC. This should be rectified. The Fukushima accident laid bare the lack of adequate preparation and the challenges that could be encountered in mounting a response. Thus, it makes considerable sense to add emergency preparedness as an objective of the HLBC and perhaps also to form a working group to assess the need for communications technologies and procedures; coordinating local, national, and international cooperation; convening bilateral or regional emergency response drills; and studying simultaneous nuclear and natural disasters.[3]

Another task that falls in both the political and technical categories, and which is discussed further below, is addressing the more immediate interim storage requirements that Korea faces, to include the potential use of dry casks. Establishing patterns of discussion and cooperation on interim storage, and socializing the Korean public and securing the buy-in of all relevant governmental and industry actors, will set an important precedent for the status of the group.

If done well, it could set the HLBC up to address some even more difficult, longer-range issues that ought to be up for discussion. In particular, both sides should start to consider "Plan B" options for the 2020-25 period in which decisions on the future of

[3] The authors thank Mark Holt for raising this issue.

pyroprocessing will be required. Currently, it does not appear such long-range thinking has been done in a systematic way by either government, even though both technical and political off-ramps may be required if, for whatever reason, the feasibility of pyroprocessing is not agreed. There are a range of considerations that should be slated for study now, ranging from multilateralization of the Korean fuel cycle to deep borehole disposal of spent nuclear fuel.

Another important prerequisite to a lasting nuclear partnership is the development of expertise to support and sustain technical and policy cooperation. This will require some bureaucratic adjustments and attention to workforce challenges. As the main counterpart in the management of the high-level dialogue with counterparts from the US Department of Energy, the ROK Ministry of Foreign Affairs will need to play a stronger role in shepherding policy through South Korea's interagency process. The Ministry of Foreign Affairs has recognized that additional resources will be necessary to support this new role. Accordingly, it elevated the existing office that dealt with nuclear trade and nonproliferation to the level of Director General to serve as a focal point for high level intergovernmental talks. The new bureau will be staffed by a larger complement of foreign ministry professionals alongside officials seconded from other agencies, including the Ministry for Trade, Industry, and Energy as well as the Ministry of Science, Information-Communication Technology, and Future Planning. These staff will be required to liaise across the many supporting agencies within the government as well as with private sector actors to effectively represent the range of South Korean stakeholders in the nuclear relationship and to effectively coordinate their activities with US counterparts.

Addressing the need to align bureaucratic structures with policy requirements is an important step, but to effectively undertake the range of interagency and foreign policy tasks required of this new bureau, it also should be staffed with requisite technical expertise. As an interim step, the Foreign Ministry could consider temporarily bringing on technical experts from the Korea Institute for Nuclear Nonproliferation and Control (KINAC) or the Korea Atomic Energy Research Institute (KAERI). Over the long term, rather than relying on consultation with specialists outside the Ministry of Foreign Affairs, the Ministry should hire and develop a technical career track that combines diplomatic experience, technical expertise, and active engagement with the policy and legal aspects of international organizations focused on nonproliferation. This can be done both through the strengthening of training programs focused on nonproliferation and as a major disciplinary emphasis and through the promotion of more active educational exchange opportunities with US (and European and other) counterpart institutions dedicated to equipping professionals to pursue careers in nonproliferation.

A further step that can be taken to enhance professional development while fostering ROK-US nuclear cooperation is the further promotion of personnel exchange through temporary assignments for American and South Korean specialists in counterpart institutions. For instance, such exchanges are already enhancing cooperation among regulators on nuclear safety and can be further enhanced by exchanges between the South Korean Foreign Ministry, the US Department of State, and the USDepartment of Energy. In the United States, this should involve greater emphasis on Korean-language training for technical and policy experts. Similarly, broader capacity building amongst civil society groups in both countries through academic exchanges and training will also foster both expertise and a broader base of support for the nuclear partnership. Existing domestic technical and policy training programs in both countries, including those involving university partnerships, could expand to involve international exchange and cross-curriculum development.

More broadly, both states need to consider the human capital challenges of sustaining nuclear energy programs decades into the future. Declining workforces will affect the full range of issues described here, meaning that attracting new talent to the field will become an increasing priority in the near term. This issue could be taken up by the HLBC, for example, with joint study of how to expand the pipeline of multidisciplinary technical and policy expertise in both countries.

Enhancing Nuclear Safety

US nuclear safety culture and contemporary nuclear regulation was shaped predominantly by two events in the 1970s: the bifurcation of the erstwhile Atomic Energy Commission in 1974 to establish an independent regulator (the Nuclear Regulatory Commission, NRC) and a promotional and research and development body (the Energy Research and Development Administration, now the Department of Energy); and the 1979 Three Mile Island accident. The latter event, in particular, resulted in a major rethinking of how to improve the effectiveness of nuclear regulation, not just of reactor design and engineering, but also operation and management practices. Today, the NRC has the primary responsibility for the former, while the US nuclear industry-initiated Institute for Nuclear Power Operations (INPO), founded in 1979, uses training and a peer-review process to ensure high operating standards and best practices across the industry. This overlap between the NRC's regulatory responsibility and INPO's self-regulation activities, though not immune from criticism, is generally assessed to have improved nuclear safety in the United States.

Korea's safety culture has evolved as its nuclear energy program has grown. It has been able to learn lessons from the United States and others that have suffered nuclear incidents and accidents, thereby reducing the potential for major environmental, economic, energy, politica,l and social consequences in Korea. Today there are numerous similarities between Korean and American approaches to nuclear safety, as well as some important differences based on the structure of Korea's nuclear industry. In particular, unlike the United States, where independent power utility corporations own and operate nuclear reactors, in Korea there is just one utility/operator, Korea Hydro and Nuclear Power (KHNP).

Following the 2011 Fukushima accident, both Korea and the United States undertook a series of measures to improve the safety of their nuclear reactor fleets. In the United States, the NRC established a near-term task force to assess potential shortcomings in the "defense in depth" philosophy for beyond design-basis events like the earthquake and tsunami that caused the Fukushima accident. For its part, shortly after the accident, Korea participated in an Integrated Regulatory Review Service (IRRS) mission of the International Atomic Energy Agency (IAEA), which highlighted several issues for Korea to address. A report from the December 2014 follow-up IRRS visit lauded Korea's efforts to implement recommended changes, in particular its establishment of an independent nuclear regulatory authority (the Nuclear Safety and Security Commission (NSSC)), backed by two competent technical authorities (the Korea Institute for Nuclear Safety (KINS) and the Korea Institute of Nuclear Nonproliferation and Control (KINAC).

Despite these notable efforts, in 2012 and 2013, Korea experienced a wave of scandals that shook confidence among the Korean public and the international community of Korean nuclear experts' approach to nuclear safety and regulation. These scandals involved the use of reactor subcomponents that had been falsely certified with forged quality control certificates. Investigations ultimately revealed that scores of parts were deemed not to meet specified quality requirements, and that, despite audit procedures, these parts had been installed both in operating reactors and those under construction. Several reactors halted operations so the parts could be replaced. There were several root causes of the scandals, among them pressure on KHNP to cut costs in order to make nuclear power competitive with fossil fuels. These problems predated the establishment of the NSSC, but suggested inherent weakness and potential for corruption in Korea's nuclear governance structure.

In the wake of these scandals, and in the face of apparent softening of domestic support for nuclear power, many believe Korea must do more to build confidence in the safety of its reactor fleet. The United States has a vested interest in Korea's nuclear safety regulation, and vice versa: Korea has applied for NRC design certification for the APR1400, a generation-III reactor that the Korean Electric Power Corporation/KHNP is building in both Korea and the United Arab Emirates. In addition to contemporary challenges, both countries face a spate of reactor license renewals and power stations to decommission, the complexity of which will increase over the next decade.

The US NRC has existed now for over four decades and possesses considerable expertise and experience in a cross-section of nuclear safety and security matters. The NSSC, in comparison, has yet to reach its five-year anniversary and is still growing in stature and competence. The NSSC is able to rely on KINS for staff and expertise, which mitigates some of the growing pains it faces, but also sows some confusion about the division of responsibility and work. Nevertheless, it has faced significant staff turnover, due in part to it being staffed by civil servants who must regularly rotate positions, which makes sustainability of its work a challenge. A related challenge for the NSSC is to recruit and retain qualified technical and policy experts, part of a broader phenomenon within Korea's civil service. For the NSSC, this issue is critical to the extent that it needs to build autonomy from entities that it has responsibility for regulating in order to avoid potential for (or at least perceptions of) conflicts of interest.

Given the importance of nuclear energy to the economies of both countries, and the deepening of commercial nuclear ties between Seoul and Washington, cooperation on nuclear safety is imperative. Understandably, there are already very deep ties between Korean and American nuclear regulators, spanning a range of topics in safety research, safeguards, physical protection, waste management, radiological safety, environmental impact, regulatory procedures, other technical issues, and the exchange of personnel. Staff from both agencies participate in frequent exchange visits and trainings. Commissioners and staff at multiple levels have close working relationships. There are multiple formal programs of cooperation and regular official meetings. Reflecting the depth of the existing relationship, the recommendations discussed below stem from specific challenges that will grow in importance over the next decade, cooperation on which would cement ties and make an important contribution to the goal of a comprehensive nuclear partnership.

Safety Culture

Best practices of safety culture are a standing feature of dialogue between US and Korean regulators. While the United States has no monopoly on safety culture—and there are certainly issues where both sides can learn from each other—in the wake of the parts scandals, many perceive that Korea has more that it can do to evolve its practices to prioritize development of a sustainable safety culture. Many experts in Korea recognize that safety culture is a high priority, but lament that steps taken to date seem more superficial and bureaucratic. There is concern in both the United States and Korea that, as the memory of the Fukushima accident fades, complacency will creep back into safety culture around the world, with potential for catastrophic consequences.

Though it is often simpler for regulatory agencies to focus on developing and strengthening technical compliance regimes, in recent years the nuclear industry has recognized the equally important need to establish and maintain a strong safety culture. Simply put, a safety culture entails the institutionalization of values—for regulators, operators, and vendors alike—that prioritizes safety over competing priorities to ensure protection of workers, surrounding communities, and the environment. Any culture is always in flux and thus a safety culture is not a finite good that can be acquired; rather, it must be practiced, reviewed, and improved over many years to become sustainable, even as it is constantly challenged by internal and external stimuli.

Safety culture must also necessarily be situated in and adapted to the broader organizational culture. In this regard, profound cultural differences between states pose an ideational challenge to the notion of a universal safety culture, and even the notion of best practices. It is one thing to stipulate that an organization's leadership must prioritize safety in the context of achieving production goals. But it is another to create processes in which accountability is shared between both management and workforce, to include protected channels for workers to communicate and raise concerns about management practices. In many states and industries, the idea that workers can dissent from an action on safety grounds is unimaginable. However, given the potential consequences of nuclear accidents, the need for procedures to handle "whistleblowing" (to report violations or raise awareness of potential problems without fear of retaliation) is now widely seen as an industry best practice. The United States has often struggled with whistleblowing, despite federal laws that protect workers who report violations. This concept is quite foreign in Korea, where the idea that workers would openly disagree with management, and that management would be subject to internal criticism, is in tension with organizational culture. Whistleblower provisions exist in Korea, but will take time to become a part of the safety culture.

Another principle now widely adopted in many advanced nuclear states is industry peer review, whereby third party expert groups audit a nuclear operator's practices in ways that don't compromise business proprietary information. INPO was formed in the United States after the Three Mile Island accident for this purpose, as was the World Association of Nuclear Operators (WANO)—of which KHNP is a member—after the 1986 Chernobyl accident. Both organizations signify recognition that a nuclear accident would have deleterious effects on the entire industry, not just the immediate facility. The 2011 Fukushima accident demonstrated this reality on a global scale, with many governments deciding to phase out nuclear power entirely, or to halt ongoing development. In this way, national and international peer reviews can raise standards and practices across the board. These third-party organizations, which serve an industry-self regulation role, are an important avenue for industry-regulator cooperation. Enhanced (in number and regularity) exchange of personnel could be a useful way to improve shared understanding of safety culture and best practices.

The 2012-13 parts scandals highlighted the need for systemic changes to address root causes of supply chain corruption in Korea, not merely deficient oversight or the culpability of senior managers. In this regard, the 2014 IRRS identified, for example, that the NSSC "should be given oversight of licensees' safety culture and integrated management systems."[4] Because Korea does not have independent utilities, rather the single utility operator KHNP, it is not clear how such oversight would work in practice; an INPO model for Korea does not seem apt. At the same time, it is apparent that developing and instituting modalities for shared responsibility for management and operations oversight between NSSC and KEPCO/KHNP is necessary, for which enhanced contacts with INPO might be useful. NSSC, KHNP, NRC, and INPO could also work together to develop guidelines for improved regulation in the areas of safety culture and management in the absence of national industry peer groups. Formation of additional advisory groups, comprised of academics, industry officials, and legal and regulatory experts, could also provide important independent review of safety and security approaches.

Third Party and Regional Outreach

Korea's winning bid to construct four reactors in the United Arab Emirates (UAE) was precedential in many respects, and one laudable feature has been the commitment by the Korean government to assist the UAE with a range of educational activities intended to build capacity for safe operation of the reactors. This has included establishing a joint education program between the Korea Advanced Institute of Science and Technology and Khalifa University of Science, Technology, and Research as well as a regulatory exchange between KINS and the UAE Federal Authority for Nuclear Regulation. This model holds considerable value for Korea to exercise broader leadership in nuclear safety regulation. If and when ROK and US firms partner for nuclear reactor projects in other countries, and even when not, there is great potential for cooperation to also help develop/strengthen regulatory capacity. Nuclear newcomers in particular will face considerable challenge in developing competence to regulate operations of very complex, modern nuclear power plants. Thus, there is an important opportunity to promote best practices and sustainable

[4] http://pbadupws.nrc.gov/docs/ML1500/ML15009A083.pdf

safety culture, recognizing that a nuclear accident in a newcomer state would at the very least seriously damage long-term commercial prospects, and perhaps worse.

Given the concentration of nuclear power in Northeast Asia (between China, Japan, and Korea), and concerns shared by many about nuclear dangers emanating from North Korea, there is a great need for regular regional discussion on nuclear safety. Several forums for such discussion exist, including the Top Regulators Meeting (established in 2008), which involves Korean, Japanese, and Chinese regulators. There is also an expanded grouping called the TRM+, which includes others such as Russia, the United States, WANO, and the IAEA. In addition, nuclear safety is a component of the nascent Northeast Asia Peace and Cooperation Initiative promoted by President Park. How these groups relate to one another and how they can contribute to shared objectives is not yet clear, given the difficulty of establishing a common political framework supported by Korea, Japan, and China. Whether through Northeast Asia Peace and Cooperation INitiative or the Top Regulators Meeting structure, finding ways for the countries in the region to discuss issues such as safety, environmental management, and emergency response is critical. Even better would be if the states involved, perhaps with Korean and American leadership, could institute programs of technical cooperation, table-top and field exercises, and the like, which would regularize cooperation and enhance confidence in each others' safety practices.

Technical Issues

In the realm of technical regulation, there is a track record of joint ROK-US work on issues of mutual interest and effect to nuclear operations in both countries. For instance, Korean and US regulators and experts (joined in some instances by peers from WANO and INPO) have investigated a series of problems with cracks in steam generator tubes in several reactors in Korea, widely blamed on the use of Inconel 600, a nickel chromium alloy that is susceptible to corrosion under high heat and pressure. Investigations such as this show how Korea and the United States, working with other countries, can strengthen regulation and operations management of nuclear power plants, which can improve capacity factors while also addressing public concerns about the safety of nuclear power.

By the same token, both states can work together to study potential future technical issues to improve mutual understanding of the regulatory and management challenges these bring. One example is issues relating to the construction of multiple large nuclear power plants at single sites. The Fukushima accident demonstrated the potential that accidents at a single site may impact more than one reactor at a time and in different ways, complicating response efforts. In this regard, the concentration of nuclear power plants at the Kori site in Korea presents an interesting case for analysis and cooperation. Presently, there are six reactors of three separate designs operating at the site (four at the original Kori site and two at the new Shin-Kori location a short distance up the coast). In addition, Korea is constructing two new reactors (the APR1400) at Shin-Kori, with plans for up to four more. If all of these plans are fulfilled, Korea could have twelve reactors at the site by the late 2020s (though the two oldest Kori reactors will be retired by then). The complexity of the site—not least the diversity of facilities of varying vintage and design—presents interesting and unusual opportunities to consider design-basis threat and accident threat analysis.

Similarly, as the Fukushima and other nuclear accidents have brought to light, the unexpected combination of singular foreseeable problems can quickly morph into complex phenomena. The potential for these chains of events deserves greater study and, potentially, adjustment of regulations and safety approaches. These include events such as explosions resulting from a buildup of hydrogen in facilities, which, after Fukushima, has been a rich area for nuclear safety research. More broadly, developing new approaches to modeling and simulation of severe nuclear accidents is an important issue for cooperation, while there is increasing awareness of the vulnerability of nuclear and related enabling facilities to cyber attack. In all of these areas, some of which are already underway between Korea and the United States, there is great potential that collaboration could have broader significance for emergency planning and response, in addition to strengthening technical and operational regulations in both countries.

Relicensing

Nuclear reactors constructed in the 1970s are now reaching the end of their planned operating lifetimes. States and utilities have powerful incentives to extend the operations of these reactors given the major capital costs involved in constructing new power plants, if continued operation can be done at highest standards of safety.

Whether and how aging reactors should be relicensed has become a critically important topic for the United States. The NRC is currently reviewing nine applications for new operating licenses for plants in the United States, with another five renewal applications anticipated in the next five years. Korea has now relicensed two of its oldest reactors, and in the next decade will decide whether to relicense five additional US-supplied reactors. Given that both the NRC and NSSC will be adjudicating license applications for similar types of reactors, information sharing makes eminent sense.

The NRC now has a rehearsed process for license renewal applications, informed by lessons learned over time that improve efficiency and enhance public opinion in the integrity of the process. Typically, operators file renewal applications prior to the expiration of the existing operation license, and in most cases operators are permitted to continue operating until the NRC completes its license review. Thus, there is no break in operations during the review period, avoiding the potential for lengthy shutdowns and restarts. The license process is handled by the NRC according to its standard procedures for public comment and transparency.

Korea is still developing its formal relicensing procedures, which the NSSC will work to streamline prior to the next batch of renewals. Two aspects of its past approach have come in for criticism. One is that the renewal applications were done only at the end of the existing license, meaning the reactor in question had to shut down for a lengthy period. This period was two-and-a-half years in the case of Wolsong 1, and this period counted against the ten-year operating period granted in the new license, such that after restart it could only operate for seven-and-a-half years. Second is that the decision making process for Wolsong was frequently delayed, there was not a regular process for public comments, and the reasons given to the public for the final decision to grant a new license were opaque. Given the considerable need to raise confidence among the Korea public in nuclear power and to address concerns raised by antinuclear lobby groups, the NSSC will undoubtedly need to refine its process to address these concerns.

The scope for continued cooperation on reactor relicensing between NSSC and NRC is quite broad. At one level, NSSC may find aspects of the US process and public relations approach attractive, and could seek cooperation with the NRC by way of training, table-top exercises, or even embedding observers to learn more about the NRC's renewal process. At another, however, the two regulators should share technical data about parameters for relicensing of reactor types that both will be reviewing. A breadth of performance and related information can help both to understand potential issues specific to different reactor types that merit scrutiny. Both states can also begin to consider longer-term regulatory issues for subsequent license renewals—for reactors to operate even beyond the initial relicensing. Finally, with both states facing strong antinuclear movements, making all licensing processes and decisions as transparent as possible without compromising sensitive information is imperative.

Decommissioning

KHNP announced in June 2015 that the ROK's oldest power reactor, Kori-1, would be decommissioned and the irradiated fuel removed from wet storage. KHNP suggested that this would be accomplished within 15 years. For both countries, the next decade will be the leading edge of a larger wave of reactor decommissioning projects, meaning there is time to develop and evolve approaches to both regulatory and operational aspects. (There is also the possibility that the United States and Korea will need to address the question of how to handle North Korea's nuclear infrastructure should there be either a denuclearization agreement or unification of the two Koreas; this issue could be a topic of joint study.)

As with relicensing, there is considerable scope for cooperation between Korea and the United States on decommissioning reactors that have reached the end of service. Decommissioning involves a multistep process to remove radioactive components from the reactor site (primarily spent fuel) for disposition, to dismantle and dispose of reactor infrastructure, and to ultimately make the property safe and suitable for re-use. A particular challenge for successful decontamination and dismantling in Korea is the shipping of spent fuel to interim storage locations at other reactor sites, or at off-site reactor interim storage facilities that do not yet exist.

The United States has some experience already, both with NRC-regulated commercial facilities and others owned and operated by the Department of Energy. To date, the United States has decommissioned 11 nuclear power plants, with 19 more in various stages of decommissioning. Another half dozen reactors are expected to reach the point of decommissioning in the next decade (if Korea opts not seek subsequent license renewals). In addition to Kori I, two additional reactors are expected to close by 2023. To date, Korea has completed decommissioning of one older research reactor.

Decommissioning is a relatively underexplored area of cooperation to date, mostly because Korea has only begun to develop the institutional infrastructure, including research activities in both KINS and KAERI and an initiative supported by Ministry of Trade, Industry, and Energy and the Ministry of Science to develop a decommissioning industry in Korea.[5] A governmental report in 2012 concluded that Korea lacked half of the technologies it needs to accomplish the task, including "decontamination and nuclear waste handling."[6] The Korean government sees in the decision to decommission Kori-1 an opportunity to develop a decommissioning market and is prepared to invest significant resources in a range of areas, from technology development to education. In this regard, Korea can learn from the US approach to date, but going forward there may be other means of cooperation, including among private industry involved in carrying out decommissioning work.

[5] http://www.businesskorea.co.kr/news/politics/12356-nuclear-leavings-korean-govt-invest-6163-billion-won-nuclear-decommissioning

[6] Daye Kim, Analysis: South Korea's New Focus on SNF and Decommissioning, *Nuclear Intelligence Weekly*, June 19, 2015.

Assuring South Korea's Nuclear Fuel Cycle

Negotiators found no issues more challenging to resolve during the 123 agreement talks than those concerning South Korea's desire to win US consent to engage in sensitive elements of the nuclear fuel—enrichment and reprocessing (pyroprocessing). US law places strong restrictions on the ability of US nuclear partners to use these technologies to "alter in form or content" US-obligated fuel, e.g. fuel supplied by the United States or irradiated in US-designed or -equipped facilities. Given the United States's strong role in the early development of Korea's nuclear program, these restrictions effectively apply to much of South Korea's fuel.

In the negotiations, Seoul sought to have more autonomy over its fuel supply and the disposition of its spent nuclear fuel. Some Korean experts went so far as to label the US restrictions an infringement of Korea's "nuclear sovereignty." US officials resisted easing these restrictions, however, primarily based on concerns about the nonproliferation implications of permitting the spread of such technology, including on policy toward North Korea. As noted above, the final agreement essentially delayed resolution of these issues for the future and delegated them to working groups under the BHLC. This tactic, while permitting conclusion of the negotiations, also ensures that fuel cycle issues will continue to be a sore point. Thus, the primary challenge for both governments going forward is to find ways and means of satisfying Korea's technical and political interest in an advanced fuel cycle, while upholding best practices for nonproliferation.

Uranium Enrichment

Of the two issues, enrichment has proven less pressing. The agreement calls on the United States to assure a reliable supply of low-enriched uranium fuel to Korea. To date, however, Korea has experienced no difficulty obtaining reliable supplies of enriched material from the international market. There is little reason to expect that it or its current and prospective reactor customers would experience market disruptions in the future. The agreement also calls for the BHLC to identify appropriate enrichment opportunities for the future. The recent establishment of an IAEA fuel bank and the existence of a US fuel bank could provide additional insurance on this score, as could the domestic stockpiling inventories of enriched material. Moreover, given the saturated nature of the enrichment market today, Seoul would likely find it difficult to establish a new domestic enterprise that could effectively compete with the well established European and Russian enrichment firms that dominate the market. Indeed, South Korea may find it more profitable to simply increase its existing stake in AREVA's new enrichment facility in France, or to purchase additional equity stakes in other projects led by Western producers.

Spent Fuel Management

Addressing Korea's spent fuel and waste management requirement is much harder. Despite the conclusion of 123 negotiations and ongoing work in the joint fuel cycle feasibility study, divergence over this issue represents the largest potential impediment to forming a bilateral nuclear partnership if the two states are not able to devise a joint path forward. Managing the issue is guaranteed to be complicated politically and technically, both because of the terms and timing of the joint feasibility study, but also because of extant gaps in Korea's fuel cycle plans. In particular, as discussed further below, though Korea has articulated a vision of using pyroprocessing to produce fuel for a fleet of sodium-cooled fast reactors, it has yet to reconcile issues related to the sequencing of the construction and operation of these very large facilities, as well as the inevitable requirement for long-term storage of high-level waste that will result from this cycle.

Devising a Korean nuclear waste management plan is also increasingly urgent because of the country's growing inventory of spent fuel and lack of concrete plans for either long-term interim storage or a permanent spent fuel repository. Korean officials and experts posit a scenario in which operating reactors may have to shut down for lack of spent fuel storage capacity in existing spent fuel pools. The ROK has more than 14,000 tons of spent fuel and discharges about 760 additional tons each year, and at least one nuclear power plant is expected to saturate in the early 2020s with current storage capacity.[7]

Korean authorities have already instituted several techniques to boost spent fuel storage capacity in existing pools. These methods include increasing fuel burn-up so spent fuel remains in the reactor longer before entering a pool, and re-racking spent fuel to more tightly pack fuel into the pools. The latter poses a seismic as well as a radiation risk and should not be considered a long-term solution.[8] They have also moved spent fuel within plants from older saturated (full) pools to newer reactors with more storage capacity, actions recommended by the Korean Nuclear Society.[9] However, this practice is more band-aid than cure, which does not obviate the need for Korea to consider building other short- to mid-term storage facilities immediately.

Regardless of Korea's fuel cycle plans, it will need to implement a long-term solution, such as a geological repository (in large underground cavities) or deep borehole (multikilometer-deep holes) disposal.[10] In order to facilitate a solution to the spent fuel problem, the ROK established in late 2013 a Public Engagement Commission (PECOS), an

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[7] Jungmin Kang, "The Search for Interim Spent Nuclear Fuel Storage in South Korea," NAPSNet Special Reports, August 31, 2015, http://nautilus.org/napsnet/napsnet-special-reports/the-search-for-interim-spent-nuclear-fuel-storage-in-south-korea/

[8] Alvarez, R., Beyea, J., Janberg, K., Kang, J., Lyman, E., MacFarlane, A., Thompson, G., von Hippel, F. N., Reducing the Hazards From Stored Spent Power-Reactor Fuel In the United States," *Science & Global Security*, Vol. 11, No. 1, 2003.

[9] Jungmin Kang, "The ROK's Nuclear Energy Development and Spent Fuel Management Plans and Options," NAPSNet Special Report, January 22, 2013.

[10] See factsheet on Deep Borehole Disposal at: http://www.nwtrb.gov/facts/BoreholeFactSheet.pdf

independent advisory body charged with developing a “consent-based national plan on SNF [spent nuclear fuel] management in order to protect people in a safe way.”[11] The PECOS issued a draft report in June 2015, which advised the government to decide on a location for a long-term storage facility by 2020, and to construct interim storage until a long-term storage facility can be established by 2051.[12] The politics of locating nuclear storage facilities in Korea are mainly domestic, although international technical cooperation and best practices for such activities may be useful.

Pyroprocessing and the Closed Fuel Cycle

The more sensitive aspect of this problem for ROK-US relations has been Korean interest in technologies for conditioning fuel for long-term storage or for recycling spent fuel as part of a closed fuel cycle. In particular, KAERI has pursued development of pyroprocessing, a reprocessing technique where plutonium separated from the fuel also contains highly radioactive fission products. (KAERI scientists argue this separated product cannot easily be used [without further separations] for nuclear weapons and that pyroprocessing is therefore more proliferation resistant than other reprocessing techniques.) In addition, part of the spent fuel that otherwise would be discarded can be fabricated into fuel for fast-neutron reactors as part of a closed fuel cycle. The KAERI plan requires several firsts: a successful pyroprocessing plant at the scale of multiple tons per year; a facility to fabricate this product from the pyroprocessing plant into fast reactor fuel; a fleet of fast reactors that would burn the plutonium and other actinides, as well as transmute long-lived iodine and technicium; and a geological repository or other long-term storage option to house separated isotopes such as cesium and strontium and other fission products. None of these technical measures have been developed successfully at commercial scales and with reasonable costs, despite decades of research in several countries with advanced nuclear programs.

Furthermore, serious studies of plutonium transmutation in the KAERI-proposed fuel cycle remain incomplete, and it is not clear how well these are coordinated with pyroprocessing capability.[13] The primary goal of pyroprocessing is to maximize the recoverability of useful actinides and uranium while removing as many fission products as possible. Fast reactors are primarily focused on increasing safety and operational performance.[14] These two aspects of operation may not be synchronized and will need to be optimized. A concern is that a potential mismatch (deliberate or unintentional) in which spent fuel is pyroprocessed far faster than the plutonium in the product is burned could lead to the stockpiling of separated plutonium as has happened in Japan. Furthermore, a lack of economic support for Pyroprocessing and Sodium-cooled Fast Reactors (SFRs) could also lead to significant delays. Therefore, any present day estimates of throughput capabilities

[11] https://www.oecd-nea.org/rwm/profiles/Korea_profile_web.pdf
[12] http://fissilematerials.org/blog/2015/06/advisory_group_recommends.html
[13] Private communication with KAERI official.
[14] Y-K Lee and M-H Kim, Nucl. Eng. Technol., 47 (2015) 47-58

may be premature, and need to be considered in the context of safety and operational performance of both technologies.

It is important to note that both the United States and Korea continue to see pyroprocessing as being in the developmental stage and do not yet have sufficient information to determine if it is appropriate for the larger throughput required to effectively minimize South Korea's spent fuel inventories. As part of the negotiations for the new nuclear cooperation agreement, the United States and South Korea have agreed to a ten-year technology-sharing joint study, formalized in 2011, to examine ways to deal with South Korea's spent fuel challenge.

Implementing Conditions in 123 Agreement and ROK-US Joint Study

The joint study is focused on examining the technical, economic, and nonproliferation (including safeguards) aspects of spent fuel management and disposition technologies, of which pyroprocessing is one of the technologies, but not the only one. However, the overwhelming emphasis has been on the technical and economic feasibility and nonproliferation suitability of pyroprocessing.[15] Following the completion of the study, both parties will "identify appropriate options for the management of spent fuel and for the development or demonstration of relevant technologies" and will conduct these consultations under the auspices of the HLBC. Should an option be selected requiring "alteration in form or content of nuclear material" (such as pyroprocessing in various fuel cycle processing scenarios), a further series of requirements must be met, specifically described in the agreement. However, much of the agreement is subject to interpretation and points of contention are likely to arise as the agreement is implemented. Given the potential for political divergence, it is worth exploring the selection criteria in some detail.

Any option must demonstrate technical viability, reasonable lifecycle costs, safeguardability, and minimal proliferation risks. In addition, it is important to emphasize that these requirements must be demonstrated for all technologies involved, principally the reprocessing facility and the fast reactor. The first technical requirement is that pyroprocessing must demonstrate high recoverability of group actinides in engineering-scale tests, as well as assure performance of the fuels through irradiation tests. Qualification of the fuel to be used in the fast reactor will be a multistage process consisting of fuel research and development, fuel performance qualification, and fuel manufacturer qualification.[16] As part of this process, KAERI is applying for a license to use the fuel and must submit a fuel qualification report to the Nuclear Safety and Security Commission (NSSC) containing detail on many aspects of the fuel.[17] In addition to the

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[15] Park Hyong-ki, "South Korea, US move forward on nuclear pact," *Korea Herald*, December 31, 2012.

[16] J. L. Snelgrove, "Good practices for qualification of high density low enriched uranium research reactor fuels.", International Atomic Energy Agency, IAEA nuclear energy series no. NF-T-5.2 (2009).

[17] The report must include details on the manufacturing process, the specific methods used to test the fuel, fuel swelling as a function of burnup, limiting irradiation conditions, corrosive behavior under irradiation and fuel disposition options etc. The MYRRHA fast reactor under development by SCK-CEN will take more

qualification of the fuel, the fuel manufacturer also needs to be able to ensure reliability within specifications, and the ability to detect noncompliant items. This requires a series of in-reactor tests to optimize fuel performance from the point of view of various safety-related aspects of fuel behavior.

Second, the selected option must also demonstrate that the total lifecycle cost is effective, taking into account social and environmental costs. The economic feasibility language in the 123 agreement lacks clarity on how noneconomic costs are weighed with respect to economic costs, meaning this issue is ripe for divergent views. For example, pyroprocessing coupled with fast reactors is expected to have a very high economic cost, but may be perceived to have relatively low environmental and social costs, depending on how effectively the option is communicated to the public.[18] KAERI has successfully framed the pyroprocessing – fast reactor solution as not requiring long-term storage. However, the highly radioactive fission products that result from this cycle still need to be stored for hundreds of years until long-lifetime fission products decay. Thus, a long-term storage option is required whether Korea pursues pyroprocessing or not. Notably missing from the description of the econmoic cost in the agreement is the inclusion of the full implementation of safeguards.

Third, the selected option must be "effectively safeguardable," meaning it must be possible to ensure timely detection of diversion and include features which impede proliferation.[19] (Some guidance can be discerned from the stringent safeguards implemented at the Monju sodium-cooled fast reactor and Rokkasho reprocessing plant in Japan.) Essential components of effective safeguards are material accountancy, process monitoring, and containment and surveillance through remote monitoring and seals, and environmental sampling to verify that there has been no deviations from the declared procedures. The efficacy of safeguards components will need to be demonstrated in a way that all parties, including the IAEA, are satisfied. Efficiencies can be gained if safeguards are built in as part of the facility-design process, but even so, as the experience with the safeguards of Rokkosho indicates, this is a very expensive aspect of the project.

The final requirement in the agreement is that any option selected that requires "alteration in form and content" must avoid "the buildup of stocks of group actinides in excess of an amount that is reasonably needed." This requirement attempts to address the concern raised above that a mismatch between throughput in the pyroprocessing, fuel fabrication, and ultimate use in a fast reactor may lead to the separation of a large quantity of pyroprocessing product containing plutonium. However, it is inevitable that, in a complex

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than a decade for fuel qualification. See schedule in: https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/documents/nuclear-fuel-engineering-tm-IPPE-2011/session_1/1_5_Delville_(et_al)_-_R&D_Program_for_the_Fuel_Qualification_of_Research_Fast_Reactor_MYRRHA.pdf

[18] Primarily because it will be possible to sequester the processing to Daejeon KAERI complex where acceptance will be high.

[19] See point 3.c under Section 6 of the new 123 agreement.

system involving multiple processing steps, there will be delays. Thus, the agreement will need to consider principles of operations to ensure that some steps can be effectively slowed or delayed to prevent a buildup of group actinides.

A further potential mismatch exists in the schedule for deploying pyroprocessing and fast reactor facilities. On paper, the first pyroprocessing facility known as the Korean Advanced Pyroprocessing Facility (KAPF) with a capacity of 100 megatons per year will begin operation in 2030s. To handle the magnitude of Korea's spent fuel accumulation, a new, larger pyroprocessing facility would need to be constructed and in operation perhaps a decade later. However, Korea's annual spent fuel discharge is expected to be ten times more than the KAPF throughput, leading to at least a decade of backlog of spent fuel for which interim storage for perhaps 10,000 megatons will be necessary.[20] There will also be a backlog of plutonium-bearing pyroprocessing product, since commercialization of plutonium burning fast reactors is not reasonably expected until at least the 2040s.

The agreement also does not place a limitation on the maximum throughput of a particular facility. This is critical because the uncertainty in throughput is related to the size of the facility. Unlike countable, discrete items such as fuel assemblies, the quantity of plutonium needs to be measured and is known only approximately. The bookkeeping difference between what is measured and expected is expressed in safeguards as the "material unaccounted for." In bulk handling facilities such as fuel fabrication and pyroprocessing facilities, the uncertainty in the material unaccounted for will depend on the size of the throughput and this may be many significant quantities of plutonium. The concern is that periodically small extractions of pyroprocessing product are undetectable due to the measurement uncertainty and may eventually add up to many significant quantities. There are ways of dealing with this issue by sampling periodically, but the option with the least risk is to restrict the throughput of singular facilities so that the uncertainty in material unaccounted for will be significantly less than a scheduled quantity, which was not discussed in the agreement. [21]

Recognizing that there are advantages to retaining some degree of ambiguity in agreements, some of the feasibility and selection criteria are sufficiently vague that future disagreement about the terms is likely. Were the parties to agree to several additional principles, it may be easier to narrow subsequent differences. For technical feasibility, these principles could include the co-location of pyroprocessing, fuel fabrication, and fast reactors at one facility and to surround it with a perimeter portal-monitoring system; the integration of a throughput monitoring system into the facility so that if a part of the process is delayed, it will not lead to separation of group actinides; and minimizing the throughput uncertainty in each facility in order to be able to determine that the quantity of plutonium in group actinides is less than a significant quantity within three weeks, the

[20] This argument is described in detail in [Braun, Chaim, and Robert Forrest. "Considerations regarding ROK spent nuclear fuel management options." *Nuclear Engineering and Technology* 45.4 (2013), pp. 427-38.
[21] Could include references and description of NDA techniques which are improving monitoring. Could mention Laser Induced Breakdown Spectroscopy and Curium measurements as a surrogate for plutonium.

timeliness criterion of the IAEA for plutonium conversion from compounds and mixtures. The countries should also consider commissioning studies (ideally joint studies) to suggest appropriate measures for judging economic feasibility and avoiding buildups of group actinides (including how any pyroprocessing/fast reactor facilities relate to broader efforts to handle spent fuel such as disposal and storage facilties).

Supporting US and ROK Nuclear Exports

Since the previous ROK-US nuclear cooperation agreement took effect in 1973, the nature, scope, and significance of the bilateral nuclear trade relationship has changed fundamentally. Whereas in the early years of the relationship, the United States built turn-key facilities in Korea, today Korea is a major player in global nuclear industry. With the APR1400, Korea holds significant nuclear intellectual property, and Korean parts are now being supplied to nuclear reactors being built in the United States. In the same vein, the contract Korea won to build reactors in the UAE was significant in many important respects, including the partnership by which US firms are subsidiaries to the project.

In some ways, the US and Korean nuclear industries are natural partners given their longstanding and deep cooperation and their complementary strengths, back by shared geopolitical views and alliance relations at the state level. Moreover, both counties' potential nuclear exports are threatened by aggressive sales practices from Russia and an emerging challenge from China. Accordingly, one of President Park's three objectives for the 123 negotiations was improving the competitiveness of Korean nuclear industry, and the final agreement includes several provisions related to trade facilitation. Indeed, many in South Korea, in particular, are eager to point to the potential virtues of ROK-US cooperation on exports.

However, the realities of the commercial marketplace, particularly in the United States, are likely to mitigate against any official attempt to steer cooperation in this direction. Although Westinghouse, for example, has long been a nuclear supplier to South Korea's nuclear industry, it also competes aggressively with Korean firms for overseas sales and is owned by the rival Japanese firm, Toshiba. In addition, unlike Korea's state-owned nuclear companies, US nuclear exporters are private companies which make their own decisions about potential export markets and partners.

That said, there remain opportunities, with some creativity required, to align US and Korean export practices and controls to enhance the export potential of the partnership. In particular, as a recent comprehensive report makes clear,[22] the United States and South Korea face stiff competition in the international market, which is exacerbated by existing laws and policies, specifically for Korean aspirations to develop the nuclear market in the Middle East. There, the United States is reluctant to sign nuclear cooperation agreements with states that do not meet the so-called "gold standard," namely forswearing developing enrichment and reprocessing capabilities. The uncertainty regarding the future of the US

[22] Fred F. McGoldrick et al, *ROK-US Civil Nuclear and Nonproliferation Collaboration in Third Countries*, The Brookings Instution, 2015.

Export-Import Bank is another challenge for the financing of US participation in major nuclear projects overseas.[23]

The US and ROK nuclear industries complement each other in a number of ways and could be strong partners in future commercial ventures—as collaboration in the UAE demonstrates. To improve cooperation in nuclear trade with third countries, there needs to be a coordinated effort to clarify export control policies to facilitate re-exports and retransfers, streamline licensing processes, and to ensure adequate financing. In this regard, Seoul would be advised to explore ways to enhance its ability to finance major projects in the future.

Turning to export controls, both the United States and Korea have been taking steps to both modernize and enhance the effectiveness of their national systems. In Korea, this has included introducing some innovative, online channels for engaging with industry in the area of dual-use goods licensing, while in the United States, this has included changes in the procedures for general and specific authorizations related to nuclear projects. As a natural complement to other elements of the partnership in nonproliferation, the two states could consider how to augment existing capacity building and export control training and enforcement efforts, both regionally and globally. The United States has done this for many years through the Export Control and Border Security and similar related programs. Korea has joined some regional efforts with the Export Control and Border Security, but could develop a more active and direct engagement strategy in the broader Asia-Pacific region alongside those it is involved with in the area of nuclear security.

Bolstering Nuclear Security and Nonproliferation

2010 marked an important shift in ROK-US collaboration on nuclear security and nonproliferation. To be sure, these issues had been a topic of discussion in annual bilateral meetings, but had rarely translated into coordinated international policy efforts. That changed, however, with the consonance of the Lee Myung-bak administration's "global Korea" policy and the Barack Obama administration's focus on strengthening global nuclear governance. The results since 2010 are clear, with Seoul and Washington sharing a common agenda and working toward shared objectives in a range of bodies, from the Proliferation Security Initiative and the Global Initiative to Combat Nuclear Terrorism to the Nuclear Security Summit process. This cooperation has allowed Korea to emerge as a global leader: in 2016, Korea will chair both the Nuclear Suppliers Group

[23] Some "Tea Party" Republicans who viewed the US government's export-financing arm as corporate welfare allowed the agency's lending authority to expire for several months in 2015. However, its authority was subsequently renewed for another four years in October of that year. See Bloomberg, "US Export Import Bank," Bloomberg Quick Take, December 1, 2015, http://www.bloombergview.com/quicktake/u-s-export-import-bank

and Missile Technology Control Regime, as well as lead an IAEA ministerial meeting on nuclear security.

The advance of cooperation in this area of nuclear policy is not accidental. Rather it reflects an idea in Korea to make nuclear security and nonproliferation a "third pillar" of the ROK-US alliance (along with security and economic cooperation). It also results from an assessment in Washington that Korea has been acquiring both the technical expertise and policy capacity to be a valued partner, and that its geographic location and position within the nuclear order could enhance efforts to strengthen global nuclear governance. In many ways, this aspect of the bilateral nuclear relationship most approaches the ideal of a partnership, in which shared objectives and combined labor can bring global dividends that meet the interests of both countries.

Today, there is robust ROK-US cooperation across a range of nonproliferation and nuclear security topics. There are regular consultations between the two governments, both bilaterally and in multilateral forums, including as part of the NSS leadership troika and at the IAEA. Nevertheless, there exist several opportunities to further strengthen the partnership.

Nuclear Security

In 2012, South Korea hosted the Nuclear Security Summit with great fanfare and skill, dedicating considerable financial and human resources to the task. Following the summit, Seoul has played an important role in several important nuclear security initiatives. In 2014, Seoul joined with the other summit hosts—the United States (2010) and the Netherlands (2014)—in putting together a key "gift basket " for the 2014 NSS, the Strengthening Nuclear Security Implementation initiative.[24] Such gift baskets are an NSS procedural innovation in which subsets of like-minded states voluntarily commit to take actions beyond those accepted by all NSS states in communiqués, work plans, etc. The Strengthening Nuclear Security Implementation initiative sought to close one of the biggest gaps in the global nuclear security framework, the absence of mandatory standards of appropriate nuclear security, by having states pledge to abide by voluntary IAEA guidance documents in this regard. Its approval by nearly two-thirds of the summit participants was perhaps the signal achievement of the 2014 NSS. The initiative was also circulated to the full IAEA membership in hopes of gathering additional adherents. [25]

At the 2012 NSS, South Korea pledged, along with the United States, France, and Belgium, to cooperate on the development of high-density low enriched uranium (LEU)

[24] *Strengthening Nuclear Security Implementation*, the Hague, 2014. https://pgstest.files.wordpress.com/2014/04/strengthening-nuclear-security-implementation_gb_2014.pdf

[25] The document is now known in IAEA parlance as "INFCIRC 869" . "Communication Received from the Netherlands Concerning the Strengthening of Nuclear Security Implementation," IAEA Information Circular, October 22, 2014, http://www.iaea.org/sites/default/files/publications/documents/infcircs//infcirc869.pdf.

fuels that could substitute for the use of HEU in high-performance reactors.[26] The countries, along with Germany, reiterated this pledge at the 2014 NSS.[27] Reducing the use of HEU in civil reactors, a potential nuclear weapon fuel, has been one of the primary goals and achievements of the NSS process. Korea's role has been to develop and produce new powders for use in these fuels based on pioneering atomization tests. Even before the summits began South Korea had eliminated the use of HEU in its own civil reactors.

Moreover, South Korea, at the 2010 NSS, pledged to establish a "Center of Excellence" in nuclear security. That center, tied to KINAC, the organization which spearheads Korea's technical efforts on nuclear safeguards, export controls, and nuclear security, led in turn in 2014 to the establishment of the International Nuclear Security Academy (INSA).[28] INSA seeks to develop nuclear security technologies, train domestic and foreign regulators, operators, and other nuclear professionals on nuclear security matters, and share nuclear security expertise with emerging nuclear states.

Nevertheless, ROK and US officials and experts acknowledge that, after the herculean efforts made for the 2012 NSS, the issue lost some urgency among top nuclear and national security decision makers, and South Korea had not played as large a leadership role that some had anticipated in global nuclear security governance. Seoul appeared to reclaim this mantle to some degree, however, when IAEA Director General Yukiya Amano announced that South Korea would be chairing the next triennial IAEA ministerial conference on nuclear security in December 2016. This position could provide South Korea with considerable leverage in shaping the global agenda on nuclear security, as the meeting will take place after what is anticipated as the last summit in 2016. It will come at a time that the IAEA is expected to take on a greater share of responsibility for advancing nuclear security within the international system.

Following from these commitments, there are four particular areas in which Korea and the United States could amplify their cooperation at the 2016 ministerial meeting and beyond to advance nuclear security.

2016 IAEA Ministerial Conference

The 2016 ministerial conference is shaping up to be a key test of whether the international community can sustain the summit process momenutum for improving nuclear security.

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[26] Belgium, France, the Republic of Korea, and the United States, *Joint Statement on Quadrilateral Cooperation on High-Density Low-Enriched Uranium Fuel Production*, 2012 Nuclear Security Summit, Seoul. https://pgstest.files.wordpress.com/2013/06/high-density-leu-fuel-production.pdf

[27] Belgium, France, Germany, the Republic of Korea, and the United States, *Joint Statement on Multinational Cooperation on High-Density Low-Enriched Uranium Fuel Development*, 2014 Nuclear Security Summit, the Hague.
https://pgstest.files.wordpress.com/2015/02/jnt_statmnt_multinatl_cooper_on_high_density_leu_fuel_developm.pdf

[28] *National Progress Report: Republic of Korea*, 2014 Nuclear Security Summit, the Hague.
https://pgstest.files.wordpress.com/2014/04/republicofkorea_pr_2014.pdf

Both the United States, as the initiator and primary force behind the summit process, and South Korea, as a summit host and chair of the meeting, have strong incentives to make the conference a success and to cooperate to that end. Among the goals on which they cooperate should be fostering broad and high-level representation at the meeting, specific pledges from attendees ("house gifts" and "gift baskets"), and winning approval for various means of sustaining substantive and political progress beyond 2016. Important goals that the United States and Korea should promote together include ensuring that the 2005 amendment to the Convention on the Physical Protection of Nuclear Material enters into force by the time of the conference and planning begins for a required review conference;[29] that additional countries sign on to the Strengthening Nuclear Security Implementation initiative; and that the conference support Korea's efforts to bolster implementation of UN Security Council Resolution 1540.[30] On the Strengthening Nuclear Security Implementation initiative, South Korea should consider hosting a meeting of initiative adherents on the margins of the conference.[31]

HEU Minimization

As noted, South Korea does not possess any HEU. Japan has been making progress toward reducing its HEU holdings as well. In line with global interest in the formation of HEU-free zones and as a form of pressure on North Korea's enrichment program, Korea and the United States could work with Japan to form a bilateral HEU-free zone and to encourage Southeast Asian states to form their own zone. [32]

Korea already plans to extend its existing work on fuel powders for foreign high-density LEU fuels for domestic efforts. Korea plans to use these powders in new LEU fuel for its new research reactor at Kijang. That reactor will be largely tasked with the production of radioactive medical isotopes, such as molybdenum-99, whose daughter product, technicium-99m, is essential in the production of isotopes for medical diagnoses. The reactor's operation alone will contribute to nuclear security in two ways: it will not only use a new high-density LEU fuel to power the reactor, it will also irradiate LEU targets

[29] For more on CPPNM, see Jonathan Herbach and Samantha Pitts-Kiefer, "More Work to Do: A Pathway for Future Progress on Strengthening Nuclear Security," *Arms Control Today*, October 2015. http://www.armscontrol.org/ACT/2015_10/Features/More-Work-to-Do-A-Pathway-for-Future-Progress-on-Strengthening-Nuclear-Security

[30] SouthKorea along with Canada helped lead a gift basket in this regard at the 2014 Nuclear Security Summit: *Joint Statement on Promoting Full and Universal Implementation of United Nations Security Council Resolution 1540* (2004) https://pgstest.files.wordpress.com/2014/04/joint-statement-on-unscr-1540_gb_2014.pdf

[31] This and a number of other useful ideas for advancing the intiative are included in Bart Dal, Jonathan Herbach, and Kenneth N. Luongo, *The Strengthening Nulcear Security Implementation Initiative*, Nuclear Secuity Governance Experts Group, October 2015. http://www.stanleyfoundation.org/nsgeg/TSF-StrenghteningNS1015.pdf

[32] For more on HEU-Free Zones, see Andrew Bienawski, Miles Pomper, and Elena Sokova, *The Case for Highly Enriched Uranium-free Zones* . Nuclear Threat Initiative, June 2015. http://www.nti.org/analysis/articles/case-highly-enriched-uranium-free-zones/

instead of HEU targets to produce molybdenum-99, contributing to a global effort to end the use of HEU in medical isotope production. [33]

Korea might be able to take this work a step further by exporting high-density fuel assemblies for use in foreign research reactors (particularly high-performance reactors in the United States or Western Europe), or by serving as an additional backup source of supply for such reactors. The United States should encourage such efforts. The United States and Western European countries are trying to develop such fuels as well, but Western Europe, in particular, is lagging considerably behind Korea. [34]

Radiological Security

In the policy realm, both the United States and Korea signed onto a gift basket at the 2014 NSS in which they pledged to secure their most dangerous (Category I) radioactive sources to IAEA standards by 2016.[35] According to their responses to a survey conducted by the Nuclear Threat Initiative, both countries have met the intent of this goal.[36] While pressing forward to continue improving the security of their own radiological sources, the two countries should increase efforts to better secure other countries' sources and, when feasible, replace them with non-isotopic alternatives.

From a nuclear security viewpoint, a primary concern is the potential abandonment of sources once their useful life has expired. This has been a factor in several other fatal incidents involving radioactive sources used in medical or experimental devices. After two to three half-lives, the source may not be useful from a medical point of view, but can still be highly dangerous from a security point of view. The United States and South Korea should organize a group of donor states, perhaps with the Global Partnership Against the Spread of Weapons and Materials of Mass Destruction, and guarantee to the IAEA the establishment of a separate fund to be used only to support the removal/repatriation of abandoned sources when all other (i.e. commercial) remedies have been exhausted.[37]

Korea has undertaken some innovative work in improving radiological security. For instance, domestically, Seoul has established an innovative system for tracking the movement of radiological sources in real time, using GPS and other technologies. At the 2012 NSS, Vietnam and South Korea (along with the IAEA) announced a Pilot Project for a

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[33] J.K Kim et al, *The KJRR, the First Research Reactor Using High Density U-Mo Fuel*, 36th International Meeting on Reduced Enrichment for Research and Test Reactors, Seoul, October 12, 2015.

[34] Ferenc Dalnoki-Veress and Miles A. Pomper (forthcoming)

[35] *Statement on Enhancing Radiological Security,* Nuclear Security Summit, the Hague, 2014. https://pgstest.files.wordpress.com/2014/04/statement-on-enhancing-radiological-security_gb_2014.pdf

[36] Andrew Bieniawski and Ioanna Iliopoulos, *Radiological Security Progress Report*, Nuclear Threat Initiative (forthcoming).

[37] For more information and the genesis of this recommendation, see Ferenc Dalnoki-Veress, George M. Moore, and Miles A. *Pomper Treatment, Not Terror: Strategies to Enhance External Cancer Treatment in Developing Countries while Permanently Reducing the Threat of Radiological Terrorism* (forthcoming).

Radioactive Source Location Tracking System in Vietnam. If successful, this system could be exported elsewhere—an effort the United States could support.[38]

In addition, South Korea's technological prowess could be harnessed to a nascent global effort to substitute non-isotopic alternatives for high-risk radiological sources.[39] This effort has been led by the United States and France; France is drafting a related gift basket for the 2016 Nuclear Security Summit.[40]

For instance, both the US National Cancer Institute and Korea's Institute of Radiological and Medical Science have partnered with the IAEA's Programme of Action for Cancer Treatment (PACT).[41] The collaboration includes regular support for training and capacity building for experts from low- and middle-income countries. But providing low-cost and secure cancer treatment for developing countries remains a particular challenge—Korea could invest resources in developing low-cost linear accelerators suitable for developing countries, perhaps working in conjunction with US national laboratories.

Given South Korea's close ties to Southeast Asia, a particular focus might be for the two countries to work with PACT to encourage the use of linear accelerators instead of cobalt-60 machines and the establish additional PACT Model Demonstration Sites for cancer treatment in that region.[42] That would allow funding for radiological security to also support efforts to tackle the growing scourge of cancer among developing countries, including those in Southeast Asia. Such countries may lack resources to both provide high-quality treatment facilities and ensure radiological security.[43]

Regional Cooperation

Undoubtedly, South Korea is positioned in Asia to be a regional leader on nuclear security and nonproliferation. INSA provides a capability and expertise to expand Korea's participation in education and training initiatives, particularly within the region. However, when paired with Korea's interest in nuclear exports, particularly in the Middle East with Jordan, UAE, and Saudi Arabia, Korea can truly be a world leader in this area.

Closer to home, South Korea was not the only regional state to pledge to establish a Center of Excellence in nuclear security; China and Japan pledged to do so as well.

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[38] *National Progess Report: Republic of Korea,* 2014 Nuclear Security Summit
[39] George M. Moore and Miles A. Pomper, *Permanent Risk Reduction: A Roadmap for Replacing High-Risk Sources and Materials*, Occasional Paper, No. 23, James Martin Center for Nonproliferation Studies, July 2015. http://www.nonproliferation.org/op-23-permanent-risk-reduction-a-roadmap-for-replacing-high-risk-radioactive-sources-and-materials/
[40] Ibid, p. 3
[41] http://cancer.iaea.org/partners.asp
[42] Vietnam already hosts such a site where the host country and PACT collaborate with the World Health Organization (WHO) and the International Agency for Research on Cancer (IARC) on cancer control, including radiation treatment.
[43] For more information, see Dalnoki-Veress, Moore, and Pomper, *Treatment, Not Terror*.

Seoul should move forward on efforts to better coordinate the work of Centers of Excellence in nuclear security in China, Japan, and South Korea, and seek to have these centers play more of a role in the nuclear security policy-making process after the NSS process runs its course.

The United States should support Korea's endeavors to be a global leader in nuclear security education and training. It can provide expertise when needed, and can share its experience with "train the trainer"-type programs. Korean and American research institutes and universities also should be woven into this picture by their governments, both to expand the pipeline of human capital available to both governments, and to reinforce a shared investment in nuclear security culture at the grassroots level.

Nonproliferation

Both Korea and the United States benefit tremendously from and are keen to strengthen global nuclear governance. Whether in nuclear security or nonproliferation, their collaborative policy efforts and joint leadership is an important contributor to the broader nuclear partnership, over and above the longstanding technical cooperation on safeguards, safety, and security. In some areas, perhaps, enhanced policy coordination might augment existing efforts. This could include, for example, developing a shared agenda to address some transparency topics and initiatives as they relate to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), including on items such as the verification initiative introduced by the United States prior to the 2015 NPT Review Conference and the IAEA Peaceful Uses Initiative. Beyond such augmentation, and looking to the future, two additional areas of potentially expanded collaboration stand out: developing a model WMD law, as described below, and coordinating efforts to address North Korea (or DPRK) nuclear scenarios.

Model WMD Law

As government officials in many states would readily admit (though probably in private), the web of international treaties, laws, practices, and standards relating to nonproliferation, export control, nuclear safety, nuclear security, and nuclear safeguards that has evolved over the last five decades is exceedingly complex. Authorities derived from these various instruments are fragmented, while implementation responsibility is divided across numerous agencies, creating bureaucratic tensions that can result in less-than-optimal policy outcomes. For states with less legal and policy capacity than exists in Seoul and Washington, the task of developing, legislating, and implementing measures to comply with the various legal and policy commitments is daunting.

In recent years, in the context of the nuclear security summits, Resolution 1540, and export control arrangements, efforts have been made to develop model laws relating to nuclear security, export control, and so forth. These are useful efforts, but they do not address this broader challenge of rationalizing a legal framework to cover all relevant areas in a holistic manner. In this context, several scholars and legal analysts in Korea have studied and debated whether to develop an encompassing legal framework that orders all of these commitments in a more logical way, taking into account the whole of the policy system as it stands today. The purpose of such comprehensive legislation would be to enhance compliance by streamlining authorities and responsibilities amongst various agencies. Whether or not Korea passes such a law will not be addressed further here, but the possibility of such an effort raises an interesting opportunity to extend ROK-US partnership on nonproliferation.

Specifically, the idea of a comprehensive WMD nonproliferation law could have considerable utility as an element of the outreach and capacity building that both countries promote around the world, particularly among nuclear newcomers. Granted, diversity among legal systems demands that any such "basic law" be tailored to the local circumstances, but nevertheless an effort to develop and promote model legislation that addresses all the elements of the nuclear regimes and sets expectations about standards of implementation would be valuable. This could become a core element of outreach strategies, joined with efforts to promote exports of nuclear power and research reactors as part of an overall engagement package designed to ensure the highest standards and implementation of best practices.

DPRK Contingency Planning

The single most important nonproliferation issue on Seoul's agenda is North Korea's nuclear program. The United States shares South Korean concerns about the direction and implications of North Korea's nuclear activities. Whether or not multilateral talks with North Korea can address this issue is beyond the scope of this paper, but Seoul and Washington will continue to coordinate their approaches.

During the mid-2000s, when the Six Party Talks to address North Korea's nuclear program were ongoing, several of the governments involved (led by the United States) developed technical plans to address the dismantlement and deconstruction of DPRK nuclear facilities. These plans understandably were driven primarily by nonproliferation and reconstitution concerns. Unfortunately, the process broke down in late 2008, and subsequently North Korea carried out additional nuclear explosive tests and expanded its nuclear infrastructure. Now, approaching ten years on, and considering that South Korea bears most of the acute safety and security threats emanating from North Korea's nuclear enterprise, it is time for both governments to revisit technical assessments and discuss how to address the range of challenges that might emerge in various contingency scenarios.

The purpose of the discussions would be to establish a new baseline technical understanding, based on available and sharable evidence, of the extent of North Korea's nuclear program, to include the location and status of facilities and materials involved, and to discuss a number of scenarios for addressing the disposition of the same. The agenda could also focus on the various policy and legal questions that derive from efforts to address the security, nonproliferation, and technical challenges. The effort need not focus on policy outcomes per se, to include probably sensitive questions related to a division of labor, rather to highlight various technical, safety, and security issues and scenarios that should inform how the governments involved should develop and coordinate their contingency planning and policy approaches.

Understandably, there is considerable sensitivity about the implications of convening any sort of official talks to discuss various outcomes in North Korea. As such, a technically oriented (as opposed to policy or intelligence oriented) discussion would need to be handled in a low-key manner. There has already been considerable work done at the track-two level on some of these questions. Perhaps the next step is to move and expand that work into a track-one-and-a-half process, which would include government officials from both sides, but would feature primarily analytical work prepared by nongovernmental experts. An important question in this regard is whether and how to incorporate Chinese experts in the discussion.

A related challenge will be how to address the human dimensions of any effort to rollback North Korea's nuclear program, including scientists and skilled technicians and program managers. Compared with the former USSR or even Iraq, there is far less knowledge about the extent of North Korean knowledge and programs in this regard—given the secrecy surrounding the DPRK and especially its nuclear program. Moreover, some programs that had established limited connections—such as those between North Korea's Kim Chaek University of Technology and Syracuse University, as well as a US-DPRK Scientific Engagement Consortium created in 2007 between Syracuse, the American Association for the Advancement of Science, the Pacific Century Institute, and the DPRK State Academy of Sciences—have been hampered by export and financial controls in the wake of the North Korean nuclear tests. Yet to prevent a dangerous brain drain in the event of ny collapse or crisis requiring US or South Korean intervention, it is important to learn as much as possible about North Korea's intellectual infrastructure and if possible establish potential contacts before such a contingency. The US government, in its interagency process, should review whether re-establishing such connections might better serve longterm US national interests and consult with Korea about such a move. One possible means of establishing connections with North Korea would be cooperation to improve North Korea's radiological safety and security.

Furthering Nuclear Science, Research, and Development

The new ROK-US 123 agreement opens the door for greater technical cooperation between the two countries. Cooperation is already strong in many nuclear technology research areas, but both countries would benefit from further sharing of nuclear technology and collaborating on nuclear research and development. For example, researchers could collaborate in the areas of spent fuel management, next generation reactor technologies, decommissioning technologies, and safety measures such as the development of accident-tolerant fuels.

Spent Fuel Management

The PECOS public engagement commission has revealed that, up until 2014, only a small portion of the funds spent on nuclear research by the government (8.4 percent) has been devoted to technologies directly involved in storing and transporting spent fuel. Instead, most of the budget has been devoted to developing pyroprocessing technology and an additional large chunk for decommissioning technologies.[44] The PECOS commission called for interim storage facilities to be built, but the South Korean industry has not prioritized this and lacks "experience and technology to build dry storage facilities and transport spent nuclear fuel casks over a long distance."[45] This capability is badly needed because all of Korea's spent fuel from light water power reactors is now in reactor pools which are nearing saturation. There is thus considerable potential for expanded collaborative work on developing these technologies with US companies like Holtec/Transnuclear or others from industry that specialize in this area.[46]

Developing indigenous cask technology would also benefit South Korea's aspirations to become a nuclear export powerhouse. Since permanent storage is difficult to site globally, and nuclear energy is growing especially in Asia, the need for spent fuel interim storage will increase. Currently, much of the spent fuel is placed in cooling pools rather than in dry storage. A recent report predicts that the number of spent nuclear fuel canisters "will exceed 10,000 in the United States alone."[47] To respond to this growing market, Hotec International has expanded their manufacturing capability by building a new plant in New Jersey. [48]

[44] https://www.pecos.go.kr/activity/news.asp?menu=10&idx=2716&state=view
[45] http://www.energyintel.com/pages/articlesummary/890216/analysis--south-korea-s-new-focus-on-snf-and-decommissioning
[46] http://www-pub.iaea.org/iaeameetings/cn226p/Session5/ID147Springman.pdf. See also cask information in: Leduc, D. R. "Dry Storage of Used Fuel Transition to Transport." (2012).
[46] G. Reitenbach, *Dry Cask Storage Booming for Spent Nuclear Fuel*, January 2, 2015, http://www.powermag.com/dry-cask-storage-booming-for-spent-nuclear-fuel/?printmode=1
[47] Ibid.
[48] http://www.bizjournals.com/philadelphia/blog/real-estate/2015/06/holetc-tech-campus-260m-factory-camden-nj.html

KAERI already has experience in constructing transfer and storage casks indigenously. [49] Therefore, since the dry storage market is growing, it may be in Korea's interest to invest in the commercial development of dry cask technology. One particular area of interest may be underground storage casks, such as Holtec International's HI-STORM UMAX, which is an underground Vertical Ventilated Module dry spent fuel storage system.[50] Underground storage systems have advantages from a "seismic, dose, security and operational perspective," particularly in sensitive areas such as in the Middle East or in Asia.[51]

All United States and Korean nuclear power plants place spent nuclear fuel into spent fuel pools, which are "robust constructions made of reinforced concrete several feet (0.6 meters) thick, with steel liners."[52] The water is about 40 feet (12 meters) deep, providing cooling as well as radiation shielding. Spent fuel pools are saturating globally, posing an additional safety concern, as spent fuel fires may occur from densely packed fuel in pools. This danger—compounded when the pools evaporate—needs to be investigated. This problem deserves greater research collaboration between Korea and the United States.

In KAERI's best-case scenario, it would be able to construct a fuel fabrication facility, a sodium fast reactor, and a pyroprocessing facility with a throughput of 100 megatons per year by 2028, later upgrading the pyroprocessing throughput to 1000 megatons per year. Even under such a scenario, an additional 10,000 megatons of storage will still be required to meet the backlog of spent fuel produced by the reactors before the fuel cycle facilities come online.[53] Chaim Braun and Robert Forrest of Stanford University have suggested a demonstration project of ten concrete storage silos, developed jointly with the United States, and suggest siting it on a military base in order to ameliorate public opposition to the project, though this may raise issues with the application of IAEA safeguards. Yet, such a site could allow both countries to showcase the potential benefits of consolidated interim storage—providing greater flexibility in case spent fuel needs to be moved quickly from reactor sites or as a temporary storage location for "stranded fuel."[54]

Deep Borehole Disposal

Recently there has been a great deal of interest in deep borehole disposal (DBD) of spent nuclear fuel as a compliment or instead of mined geological repositories. In DBD, nuclear waste is placed into the bottom section of deep boreholes five kilometers deep, where the upper three kilometer section is backfilled with alternate plugs of compactified Bentonite

[49] Yook, Daesik, Spent Fuel Management in Korea, Slide 31, KINS-NRC Information Exchange, January 2013. http://pbadupws.nrc.gov/docs/ML1304/ML13046A076.pdf
[50] http://www.holtecinternational.com/productsandservices/wasteandfuelmanagement/hi-storm/hi-storm-umax/
[51] http://www.inmm.org/30th_INMM_Spent_Fuel_Seminar/5249.htm
[52] http://www.nrc.gov/waste/spent-fuel-storage/faqs.html
[53] Braun, Chaim, and Robert Forrest. "Considerations regarding ROK spent nuclear fuel management options." Nuclear Engineering and Technology 45, no. 4 (2013): 427-438.
[54] http://energy.gov/sites/prod/files/2013/04/f0/brc_finalreport_jan2012.pdf. Stranded fuel is the term for fuel from shutdown reactors that still remains on site.

clay, cement, and crushed rock. It is reasonable to assume that, because of the isolation of the waste compared to mined geological repositories, DBD may be more acceptable to the public. However, not much specific research has been done on the public acceptability of the method and is needed. A greater depth than mined geological repositories may "diminish the likelihood of failure scenarios in which radionuclides are able to mix with groundwater and eventually propagate into the environment."[55]

In 2011, Sandia National Laboratories performed an extensive review of DBD, describing in detail the design and the procedures for deep borehole placement and a preliminary estimate of the cost.[56] The United States Blue Ribbon Commission, in their final report, encouraged further research and development, stating that DBD may be "a disposal alternative for certain forms of waste that have essentially no potential for re-use."[57] The US Department of Energy has launched a Deep Borehole Disposal Field Test currently in progress to determine the feasibility of the deep borehole disposal concept, which is conducted with the participation of six different national labs, universities, and other entities.[58] The group also includes participation of several international partners, including KAERI, for borehole sealing investigations performed at the KURT (KAERI Underground Research Tunnel) facility in Yusung Gu, Deajeon, Korea.[59] According to a briefing in October 2015, drilling is expected to start in September 2016.[60] Expanded involvement by KAERI in the DBD research done in the United States should be considered in order to develop a better understanding of the feasibility of conducting a field test in Korea in the future.

In the United States, DBD is being considered an option for emplacement of cesium and strontium capsules currently stored at the Hanford Site. In Korea, even if pyroprocessing will be conducted, the separated high activity waste which results could be emplaced in a DBD, which will be dominated by cesium and strontium whose isotopes have half-lives of about thirty years. An advantage of using DBD to dispose of reprocessing waste is "that it does not stress the performance of borehole isolation over millennia, but only over

[55] Dalnoki-Veress, Ferenc, and Miles A. Pomper. "Dealing With South Korea's Spent Fuel Challenges Without Pyroprocessing." *Arms Control Today* 43, no. 6 (2013): 16.

[56] Arnold, B.W., P.V. Brady, S.J. Bauer, C. Herrick, S. Pye and J. Finger 2011. Reference Design and Operations for Deep Borehole Disposal of HighLevel Radioactive Waste. SAND2011-6749. Sandia National Laboratories, Albuquerque, NM. October, 2011.

[57] Hamilton, L. H., B. Scowcroft, M. H. Ayers, V. A. Bailey, A. Carnesale, P. V. Domenici, S. Eisenhower et al. "Blue Ribbon Commission on America's Nuclear Future: Report to the Secretary of Energy." Blue Ribbon Commission on America's Nuclear Future (BRC), Washington, DC (2012).

[58] http://www.nwtrb.gov/meetings/2015/oct/gunter.pdf

[59] http://www.nwtrb.gov/meetings/2015/oct/sassani_hardin.pdf

[60] http://www.nwtrb.gov/meetings/2015/oct/gunter.pdf

centuries."[61] A preliminary study of siting a DBD facility in Korea was performed by Dr. J. Kang for the Nautilus Institute. [62]

ROK-US Research and Development in Generation IV Technologies

Korea also has an extensive research and development program in advanced reactor technologies and aims to complete a Very High Temperature gas-cooled Reactor (VHTR) prototype reactor by 2020 and a 150 MWe (400 MWth) sodium-cooled fast reactor (PGSFR) by 2028. The purpose of the VHTR technology is to reduce carbon dioxide emissions by producing hydrogen using the reactor's heat.[63] Korea has taken a leading role in the Generation-IV International Forum and has collaborated with the United States in the development of both of these technologies.

KAERI and Argonne National Laboratory recently signed a memorandum of understanding pertaining to the PGSFR for "developing the reactor system while the Korean engineering and construction firm KEPCO E&C is designing the balance of the plant."[64] Argonne will design the "plant control system, electromagnetic pump design and other subsystems to augment KAERI's capabilities. Argonne will also support KAERI with safety analysis and the licensing process by the Korean regulatory authority."[65] The reactor's purpose will be to provide electricity for the grid and evaluate the fuel's usefulness for transmuting transuranics. The United States developed the SFRs and an integrated, co-located pyroprocessing-based fuel cycle facilities upon which the PGSFR is based. Although the United States discontinued the original project in the 1990s, both countries still maintain a strong interest in novel SFR technologies and continue to collaborate on pyroprocessing and SFR technologies.

Korea is also developing another SFR technology, the Korea Advanced Liquid Metal Reactor in parallel with the PGSFR, which is of a different design. KAERI plans to start testing a sodium test loop for thermal-hydraulic studies in 2019.[66] Korea intends to

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[61] http://www.nwtrb.gov/meetings/2015/oct/garwin.pdf

[62] J. Kang, "Exploration of the Potential for Deep Borehole Disposal of Nuclear Wastes in South Korea: An Update," Nautilus Institute Report, July 2014. http://nautilus.org/napsnet/napsnet-special-reports/update-potential-for-deep-borehole-disposal-of-nuclear-wastes-in-rok/

[63] For a recent review see: Li Fu, Very High Temperature Reactor GIF Symposium, San Diego November 15-16, 2012. https://www.gen-4.org/gif/upload/docs/application/pdf/2013-10/very_high_temperature_reactor.pdf

[64] World Nuclear News, August 27, 2014. http://www.world-nuclear-news.org/NN-Cooperation-deal-to-develop-advanced-reactor-2708141.html

[65] Argonne National Lab's Yoon Il Chang interviewed by Nuclear Street. http://nuclearstreet.com/nuclear_power_industry_news/b/nuclear_power_news/archive/2014/09/10/exclusive_3a00_-q-_2600_-a-with-yoon-chang_2c00_-head-of-anl_2f00_kaeri-project-to-develop-sodium_2d00_cooled-fast-reactor-091001

[66] Hyung-Kook Joo, Status of Fast Reactor Technology Development in Korea, The 48th IAEA TWG-FR Meeting, Obninsk, Russia, 25-29 May 2015.

develop a prototype SFR based on this advanced liquid metal technology by 2028, which does not leave much contingency for delays. Therefore, one potential topic for enhanced cooperation would be in development of a smaller pilot facility to "acquaint engineers with operational issues."[67]

Accident Tolerant Fuel Research and Development

Since the 2011 Fukushima accident, there has been considerable interest in developing accident tolerant fuels (ATF), intended to demonstrate enhanced safety performance over regular light-water reactor (LWR) fuel during an event such as loss of coolant accident. As stated by KAERI: "Since practically no reactor design can ensure against all contingencies in advance, and thus the possibility always exists that unexpected events could occur, ATF that could mitigate the consequences of an accident, especially a severe one, are being developed worldwide."[68] The main goal of ATF is to perform better when a loss-of-reactor coolant or other accident threatens to overheat the fuel. In a typical LWR design, if the fuel becomes hot enough, the zirconium cladding causes the water to decompose and the flammable gas hydrogen to evolve, which can trigger an explosion if the concentration of hydrogen is high enough. Similarly, if fuel overheats, the cladding may no longer retain volatile fission products such as cesium and iodine, the release of which can threaten public health. A special expert group within the Nuclear Energy Agency of the Organization for the Economic Cooperation and Development has been formed to initiate an international effort to develop such fuels with active participation from the United States and ROK and about ten other countries.

The United States and Korea are conducting experiments with novel cladding materials such as advanced steels (FeCrAl) and various types of stainless steels. They are also experimenting with novel oxide fuels with additives that can improve the ability of the fuel rods to shed excess heat (thermal conductivity) and retain the fission products within the fuel assembly, such as by using particle fuel dispersed in a ceramic or metallic matrix. The United States has many different groups and organizations working on ATF, including five national labs, research groups at nuclear engineering schools and from industry.[69] It would be useful for these experiments, and especially technology sharing with Korean researchers, to continue. Most ATF require increased enrichment to account for replacing cladding with neutron absorbing molybdenum or other materials as well as other reasons.

[67] Braun, Chaim, and Robert Forrest. "Considerations regarding ROK spent nuclear fuel management options." *Nuclear Engineering and Technology* 45, no. 4 (2013): 427-438.
[68] Koo, Yang-Hyun, Jae-Ho Yang, Jeong-Yong Park, Keon-Sik Kim, Hyun-Gil Kim, Dong-Joo Kim, Yang-Il Jung, and Kun-Woo Song. "KAERI's Development of LWR Accident-Tolerant Fuel." *Nuclear Technology* 186, no. 2 (2014): 295-304.
[69] https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/documents/TWGFPT/2014/Presentations/10-Overview_of_International_Activities_in_Accident_Tolerant_Fuel_Development_for_Light_Water_Reactors_(Sh._Bragg-Sitton).pdf

The enrichment can be as high as 7-8 percent which exceeds the usual commercial levels (maximum of 5 percent enriched). Furthermore, if molybdenum is used as cladding or for UMo fuel, it is useful to remove the Mo-95 through gas centrifuge enrichment of lighter or heavier molybdenum isotopes. Mo-95 is a strong neutron absorber so that higher uranium-235 enrichments are required to account for the Mo-95 absorption.

High Assay Low Enriched Uranium Fuels

As noted above, several different types of planned reactors and fuels of interest to both the United States and South Korea require enrichment levels beyond the maximum 5 percent enrichment level currently produced by commercial enrichers. These include the Traveling Wave Reactor, research reactors using high-density LEU fuels, Korea's planned SFR, and accident-tolerant fuels. Given other demands for supplies of such material, currently produced by downblending US HEU, Korea should work with the United States to make sure that a supply of higher than 5 percent LEU fuel will be available for the United States, South Korea, and the global market when needed.

SMART Reactor Research and Development

It is often said that the emergence of Small Modular Reactors (SMR) will energize the nuclear energy market. They have lower power, a smaller footprint than large power reactors, can be installed in modules, and boast a far cheaper price tag.[70] These and other advantages are believed to make them accessible to a larger market, especially in lower income countries. However, there have been some growing pains in the development of SMRs in the United States. The US nuclear power firm Babcock & Wilcox has reduced its planned investment substantially, and Westinghouse stopped SMR development in 2014. In the United States, only NuScale is poised to submit licensing documentation to the NRC in 2016. It seems that investors are waiting to see what will happen with the nuclear industry as a whole: they know that the cost of the reactors will decrease as the number of sales increases but the industry's future particularly in the United States has become a matter of concern. [71]

South Korea has been a leader in this regard. KAERI has developed the SMART (System integrated Modular Advanced Reactor) reactor which has a rated thermal power of 100 MWe and is capable of desalinating water to produce 40 kilotons of fresh water per day.

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[70] J. Concha, "Can SMRs Lead the U.S. Into A Clean Energy Future?," *Forbes*, Feb 16, 2015. http://www.forbes.com/sites/jamesconca/2015/02/16/can-smrs-lead-the-u-s-into-a-clean-energy-future/#3123a71126c3

[71] J. Green, "Saudi Arabia's nuclear power program and its weapons ambitions, *Nuclear Monitor*, 791, 2014. www.wiseinternational.org/nuclear-monitor/791/saudi-arabias-nuclear-power-program-and-its-weapons-ambitions. The Obama administration has just announced a strategy to address many of the problems with bringing SMR's to market. In particular the slow licensing of the many designs as well as other actions. See: https://www.whitehouse.gov/the-press-office/2015/11/06/fact-sheet-obama-administration-announces-actions-ensure-nuclear-energy

To be sure, demand for such reactors within Korea has been lukewarm: KEPCO has no immediate plans to deploy these reactors in Korea. However, SMART was the first reactor to be fully licensed and South Korea has recently signed a memorandum of understanding (MoU) with Saudi Arabia's King Abdullah City for Atomic and Renewable Energy (KACARE) to conduct a feasibility study to build two SMART reactors in Saudi Arabia. The MoU states that Saudi Arabia will co-own the intellectual property rights to the Korean designed technology and will work together to commercialize the technology. [72]

While the construction of SMART reactors in Saudi Arabia is good for promoting the commercialization of the technology, it does pose a proliferation concern which must be addressed. South Korea has promoted these reactors as being inherently proliferation resistant based on the length of time between refueling (three years) and it is use of LEU fuel.[73] However, the reactor produces a considerable proportion of plutonium, and all grades of plutonium should be considered proliferation sensitive, especially if technology is sold to a country that has shown interest in nuclear weapons. [74]

Korea has launched a company called "SMART Power" whose purpose is to "market SMART technology overseas, conducting joint feasibility studies with interested customers, and continuing design work to make the reactor technology "more economically feasible." [75] Cooperation betwee Korea and the United States to address the issue of the proliferation sensitivity of the SMART reactors which will help with marketing the reactor in the Middle East and other areas of proliferation concern. Stipulations that the fuel may not be reprocessed would form an important legal bulwark against proliferation, but more could be done through enhanced safeguards or developing proliferation resistant fuels, specifically for SMART reactors.

[72] http://www.kacare.gov.sa/en/?p=1667
[73] See page 21. https://aris.iaea.org/sites/..%5CPDF%5CSMART.pdf
[74] See discussion in: Richard Garwin, Reactor-Grade Plutonium Can be Used to Make Powerful and Reliable Nuclear Weapons: Separated plutonium in the fuel cycle must be protected as if it were nuclear weapons, August 1998. https://fas.org/rlg/980826-pu.htm
[75] Green, "Saudi Arabia's nuclear power program and its weapons ambitions."

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Acronyms

123 agreement	Agreement for Cooperation Between the Government of the United States of America and the Government of the Republic of Korea Concerning Peaceful Uses of Nuclear Energy
AEC	Atomic Energy Commission. Highest-ranking decision-making body on policy issues and utilization of nuclear energy. The AEC is composed of between nine and eleven members, representing various sectors of the government, academia and industry.
APR1400	An advanced Generation III pressurized water nuclear reactor designed by the Korea Electric Power Corporation (KEPCO). It was developed from the earlier OPR-1000 design and also incorporates features from the US Combustion Engineering (C-E) System 80+ design.
ATF	Accident Tolerant Fuels. Fuels under development that do not deteriorate under extreme temperatures, which can occur during a loss of coolant accident.
DBD	Deep Borehole Disposal. A form of disposal similar to geological repository where high-level radioactive waste is emplaced deep underground in 5 kilometer- (3.1 miles) deep boreholes.
DPRK	Democratic People's Republic of Korea (North Korea)
HEU	Highly enriched uranium. Uranium enriched to at least 20 percent uranium-235 (a higher concentration than exists in natural uranium ore).
HLBC	High-Level Bilateral Commission. Co-chaired by the vice minister of foreign affairs in South Korea and the deputy secretary of energy in the United States, the HLBC is a way for both states to bring high-level attention to nuclear fuel cycle issues.
IAEA	International Atomic Energy Agency
INPO	Institute for Nuclear Power Operations, established in 1979 by the US nuclear power industry following the investigation of the Three Mile Island accident. INPO sets industry-wide performance objectives, criteria, and guidelines for nuclear power plant operations that are intended to promote operational excellence and improve the sharing of operational experience between nuclear power plants. INPO is funded entirely by the US nuclear industry.
INSA	International Nuclear Security Academy, a division of KINAC.
IRRS	The IAEA's Integrated Regulatory Review Service is designed to strengthen and enhance the effectiveness of the national regulatory

infrastructure of states for nuclear, radiation, radioactive waste, and transport safety. In particular, IRRS missions focus on both regulatory technical and policy issues in the light of international guidelines embodied in the IAEA Safety Standards and of good practices observed in other states.

KAERI — Korea Atomic Energy Research Institute, the main research and development laboratory in Korea responsible for developing nuclear power reactor technology. It is managed by MSIP.

KAPF — Korean Advanced Pyroprocess Facility.

KEPCO — Korea Electric Power Corporation. Largest electric utility in South Korea, responsible for the generation, transmission, and distribution of electricity and the development of electric power projects including those in nuclear power, wind power, and coal. KEPCO is responsible for 93 percent of ROK's electricity generation.

KHNP — Korea Hydro and Nuclear Power, a subsidiary of KEPCO. It operates large nuclear and hydroelectric plants in South Korea, which are responsible for about 40 percent of the ROK electric power supply.

KINAC — Korea Institute for Nuclear Nonproliferation and Control, a government technical body that promotes the enhancement of nuclear transparency in the ROK—particularly regarding IAEA safeguards and nuclear security recommendations—and contributes to international non-proliferation efforts.

KINS — Korean Institute of Nuclear Safety, a nuclear regulatory expert organization that aims to protect the public and the environment from the harmful effects of ionizing radiation.

LEU — Low-enriched uranium. Uranium that contains a uranium-235 concentration between 0.7 percent and 20 percent.

LWR — Light-water reactor, the most common type of commercial reactor. It uses water as both a coolant and moderator.

NPT — Treaty on the Non-Proliferation of Nuclear Weapons. Entered into force in 1970, this international treaty's objective is to prevent the spread of nuclear weapons and weapons technology, to promote cooperation in the peaceful uses of nuclear energy, and to further the goal of achieving nuclear disarmament and general and complete disarmament.

NRC — US Nuclear Regulatory Commission, an independent agency of the United States government, established by the Energy Reorganization Act of 1974, and began operations on January 19, 1975. As one of two successor agencies to the United States Atomic Energy

	Commission, the NRC's role is to protect public health and safety related to nuclear energy. It oversees reactor safety and security, reactor licensing and renewal, licensing of radioactive materials, radionuclide safety, and spent fuel management including storage, security, recycling, and disposal.
NSS	Nuclear Security Summit. Launched by President Barack Obama in 2010, the NSS is a meeting of about fifty world leaders aimed at preventing nuclear terrorism around the globe. Two other summits took place in 2012 and 2014, with the final summit planned for March 2016.
PACT	IAEA's Programme of Action for Cancer Treatment, aimed at coordinating a global response to support low and middle income states in implementing comprehensive national cancer control programs.
PECOS	Public Engagement Commission, an independent advisory body established in October 2013 to advise the government of South Korea on nuclear issues. The body issued a draft report that outlined its recommendations regarding spent nuclear fuel management in South Korea in June 2015.
PGSFR	Prototype Generation-IV Sodium-cooled Fast Reactor, an advanced reactor, partly based on the successful EBR-II prototype.
ROK	Republic of Korea (South Korea)
SFR	Sodium-cooled Fast Reactor, a type of reactor that does not use a moderator to slow neutrons down and uses liquid sodium as a coolant.
SMART	System integrated Modular Advanced Reactor
SMR	Small Modular Reactors, nuclear power plants that are smaller in size (300 MWe or less) than current generation base load plants (1,000 MWe or higher). These smaller, compact designs are factory-fabricated reactors that can be transported by truck or rail to a nuclear power site.
UAE	United Arab Emirates
VHTR	Very High Temperature gas-cooled Reactor. This advanced reactor concept uses a graphite-moderated nuclear reactor with a once-through uranium fuel cycle.
WANO	World Association of Nuclear Operators, an international, non-profit group of nuclear power plant operators whose primary emphasis is achieving the highest possible standards of nuclear safety.

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