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Reducing Proliferation Risk

The coming expansion of nuclear power can be a security as well as an environmental blessing, but only if it comes without a great increase in the risk of the proliferation of nuclear weapons.

The use of nuclear energy to produce electricity is expanding worldwide, and as it does the danger that nuclear weapons will also be developed is increasing as well. Historically, most of the nuclear power industry has been concentrated in the United States, Europe, and Japan. Today, however, many countries are planning reactors and making choices about their fuel supply that will determine the risk of weapons proliferation for the next generation. Although the countries that traditionally set the tune for nuclear power policies have waning influence on who goes nuclear, they may be able to affect how it is done and thus reduce the proliferation risk. The key is rethinking the fuel cycle: the process by which nuclear fuel is supplied to reactors, recycled, and disposed of.

There is no nuclear fuel cycle that can, on technical grounds alone, be made proliferation-proof against governments bent on siphoning off materials to make weapons. Opportunities exist for the diversion of weapons-usable material at the front end of the fuel cycle, during which natural uranium is enriched to make reactor fuel. Opportunities also exist at the back end of the cycle to extract fissile material from the spent fuel removed from reactors. Although a complete siphon-proof system is impractical, one maxim can guide our thinking on lowering the odds of proliferation: The more places in which this work is done, the harder it is to monitor.

Weapons have been produced from both ends of the fuel cycle by countries as diverse in industrial capacity as India, Israel, North Korea, Pakistan, and South Africa. (South Africa abandoned its nuclear weapons in 1991. Libya started down the weapons road and gave it up. Iran's intentions are still uncertain.) The level of technical sophistication of these countries ranges from very low to very high, yet all managed to succeed in building a weapon once they had the fissile material. The science behind nuclear bombs is well known, and the technology seems to be not that hard to master or acquire.

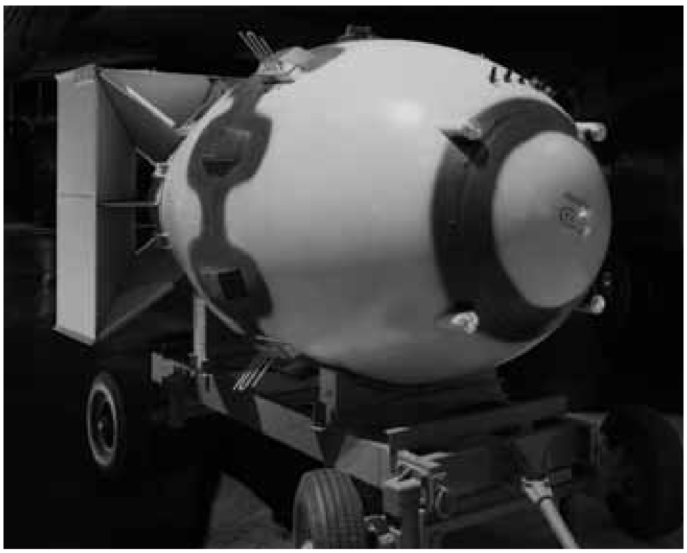
There is no shortage of good ideas for creating a better-controlled global fuel cycle based on minimizing the number of fuel-handling points. Mohamed ElBaradei, head of the International Atomic Energy Agency (IAEA), and President Bush, for example, have both suggested plans that would internationalize the fuel cycle. The problem is that such ideas, although good in theory, need to get the incentives for participation right. So far, these plans are the result of the nuclear haves talking among themselves and not talking to the nuclear have-nots. While the talking proceeds, governments that are new to the nuclear game are concluding that they may have to build their own fuel supply systems that are less dependent on suppliers with their own political agendas. That outcome must be avoided. The problem needs urgent attention because it will take a generation to build a credible international fuel cycle. If serious efforts do not begin today, then the have-nots will probably build their own fuel supply systems and the dangers of proliferation will become much greater.

Serious plans to tame proliferation by nation-states must include carrots to make any system attractive and sticks to provide effective monitoring and credible sanctions. Currently, incentives are in short supply, inspections are not as rigorous as they could be, and there is no consensus on the rigor of sanctions that should be applied.

A well-designed international fuel cycle could create many carrots. The cost to a country that is new to nuclear power of setting up its own enrichment or spent-fuel treatment facilities is enormous. Countries with a new or relatively small nuclear program will strongly favor an international approach if they come to trust the suppliers of the fuel and other needed services. Today, the only places to purchase enrichment services are the United States, Western Europe, and Russia. This group is too narrow in its political interests to constitute a credible supply system. Others must be encouraged to enter the fuel supply business. A well-managed system in China would add considerably to political diversity in the supply chain.

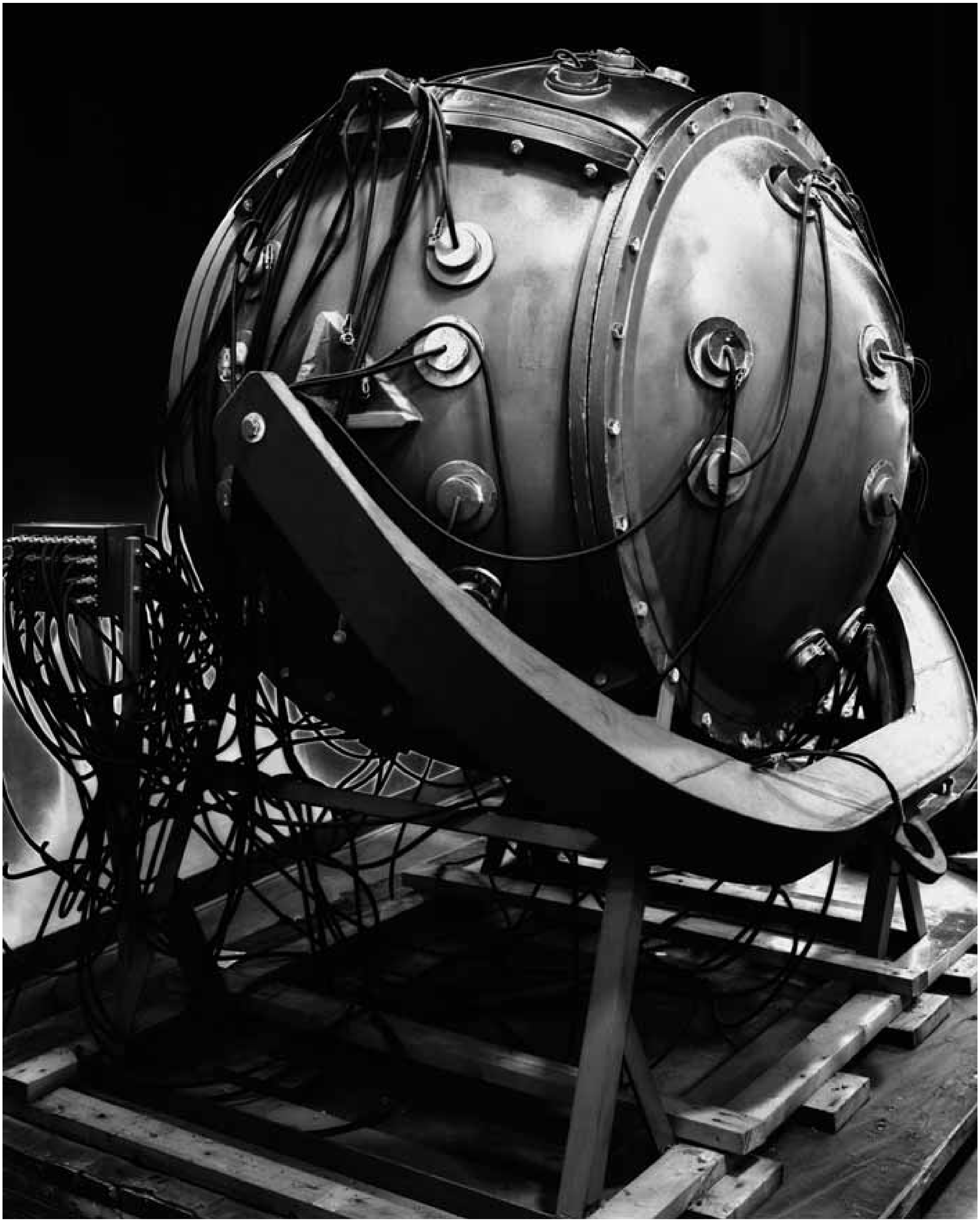
The back end of the fuel cycle is technically more complicated to deal with and so are the systems that need to be implemented. The spent-fuel stage cannot be made as bulletproof as enrichment, but it can be improved through the same approach that is needed at the front end: a credible international system.

The coming expansion of nuclear power can be a security as well as an environmental blessing (after all, nuclear energy is entirely free of greenhouse gas emissions and can help us deal with climate change), but only if it comes without a great increase in the risk of the proliferation of nuclear



Above: MARTIN MILLER, *"Fat Man" (Nagasaki Atomic Bomb) 1945*, Archival pigment print, 40 x 50 inches, 2007.

Opposite: MARTIN MILLER, *"The Gadget" (Trinity Atomic Bomb) 1945*, Archival pigment print, 50 x 40 inches, 2007.



MARTIN MILLER, *B-2 Strategic Bomber 1989*, Archival pigment print, 40 x 50 inches, 2007.

weapons. It is clear to scientists like me that we cannot fix the proliferation problem ourselves. We can tell the diplomats where the biggest holes are and suggest how they might be plugged. The plugs are not technical, but political and diplomatic. What is needed is for the haves to spend less time talking to each other and begin more serious discussions with the have-nots on what a new internationalized fuel cycle should be.

Enrichment: Plugging leaks

Designing a fuel-supply system requires focusing on light-water power reactors (LWRs), which make up nearly all of the nuclear power plants. Although there are many variants of advanced LWRs being developed and marketed these days, as far as proliferation risk is concerned, they are all basically the same, relying on enriched uranium for fuel and producing fissile plutonium in their spent fuel.

Natural uranium has only a tiny fraction of the isotope (U-235) that LWRs need to make energy commercially. All LWRs need fuel that is enriched by a factor of six or seven to a level of 4 to 5% U-235. Any enrichment plant has the potential to enrich far beyond this target to the level needed to make a nuclear weapon. To make a reliable weapon, a potential proliferator will want 90% enriched material. This is front-end proliferation.

If a facility big enough to do the enrichment for a power plant already exists, it takes only a small increment in capacity to produce the material for a few uranium weapons. A nuclear power plant with an output of 1,000 megawatts of electricity [one gigawatt of electricity in international units (1 GWe)] requires about 20,000 kilograms (kg) of new enriched fuel per year, which would come from nearly 200,000 kg of natural uranium. Diverting only about 1-20th of this material would be sufficient to produce enough highly enriched uranium to make a single weapon.

The preferred technology for enrichment today is the gas centrifuge. These are not simple devices, and the technology of the modern high-throughput centrifuge is not

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easy to master. Those of the Kahn network used by Pakistan for its uranium weapons are primitive by today's standard. Making enough fuel for Iran's Bushehr 1-GWe reactor would, for example, need about 100,000 of the Pakistan P1 centrifuges, requiring a very large plant. But it takes only about 1,500 more centrifuges fed with the output of the big plant to make enough 90%-enriched material for one uranium weapon per year.

The Iranian IR-2 centrifuge is said to be about three times more effective than the P1. Iran is clearly mastering the technology. The most modern Western centrifuges are still more efficient by another factor of 3 to 10. The proportions stay the same, however. A plant based on IR-2s would require 35,000 units to fuel a power reactor, but only about 250 more to produce a weapon.

Iran's insistence on developing its own enrichment capacity has led to much discussion on how to do enrichment in a more proliferation-resistant fashion. The main focus has been on preventing nations new to nuclear power from developing their own enrichment capacity, by creating an attractive alternative. The exemplar is South Korea, which obtains 39% of its electricity from nuclear power and by its own choice does no enrichment of its own. It has saved a great deal of money by not enriching. Making this kind of arrangement acceptable to countries that are not firm allies of those with enrichment facilities requires some mechanism to guarantee the fuel supply. Without such a mechanism, it is doubtful that any sensible country interested in developing nuclear power would agree to a binding commitment to forego its own enrichment capability. The tough cases are not the South Koreas of the world, but states such as Malaysia, Indonesia, and Brazil (which has two reactors and talks of building more), with growing economies that are more suspicious of their potential suppliers.

ElBaradei, in his proposal, envisions the IAEA serving in some way as a guarantor of fuel supply to those nations willing to forego developing their own enrichment capacity. There are two issues that need to be addressed if such a scheme is to be accepted. The big issue is sufficient diversity of supply, so that countries foregoing their own enrichment facilities are reasonably assured of access to fuel when needed. A secondary issue is the control of entrants into the supply chain. If the forecasts of the expansion of nuclear power are anywhere near correct, there is a great deal of money to be made by supplying enrichment services, and it may be that new entrants into the business will want a share.

Security of supply really comes down to a diversity of suppliers, both politically and commercially. The world has been through this before with oil during the 1970s. OPEC was the dominant world supplier and cut off supplies because of Western support for Israel. Today, the oil supply comes from more places, and supply concerns are less about oligopoly control than about the adequacy of resources.

At present, there are only four places to purchase enrichment services: the United States Enrichment Corp. (U.S.-owned and operated), Eurodif (internationally owned but French-operated), URENCO (internationally owned and operated), and Russia (state-owned and operated). This is not much diversity of supply, either politically or commercially.

The issue in the ElBaradei model is how to make the security of supply credible to countries that purchase enrichment rather than doing it themselves. No nation can afford to put a major part of its electricity supply at the mercy of a supplier who might cut it off for political reasons.

The IAEA proposal includes the establishment of an emergency fuel bank, which would ensure that those who agreed to forswear enrichment would be guaranteed continuity of supply. The way to do this is to stockpile enriched uranium. With facilities in 16 different countries that can fabricate fuel from enriched uranium, the necessary diversity of services is ensured. It takes only about 90 days to fabricate a fuel reload for a 1-GWe reactor if the mechanical parts and assemblies are available. If they have to be ordered and newly built, the entire process can take much longer. The security of supply is ensured if each reactor has the spare component parts for a reload minus the enriched uranium, and the IAEA can supply the enriched uranium at short notice. The new fuel could then be supplied in 90 days.

An expansion of nuclear power requires an expansion of enrichment services. Even if the fraction of electricity coming from nuclear energy (now 16% worldwide) is to remain constant as energy use increases, the world will need at least a twofold expansion in enrichment services by the year 2050. Many new suppliers can enter the business. China should enter the commercial enrichment business to enhance political diversity, and other countries should be encouraged to develop internationally owned and operated enrichment services under appropriate safeguards to increase the diversity of supply. New actors such as Australia, Canada, or Mongolia, which have large supplies of uranium, may want to move up the profit chain by entering the enrichment field and not merely supplying uranium ore.

President Bush has proposed an even broader proliferation prevention scheme that looks at both the enrichment and spent-fuel treatment phases of the nuclear fuel cycle. The Bush system envisions that only the countries with existing facilities would serve as the suppliers of enrichment services. But this does not increase the diversity of suppliers and might be seen by potential users as too risky. There have been discussions with other countries as part of a program called the Global Nuclear Energy Partnership (GNEP). However, these discussions have only begun to engage some of the countries that might start a nuclear power program in the future. GNEP will not go anywhere as a concept, much less as a real program, until these talks get serious. Doing enrichment only in those countries that already do it is unlikely to work.

Spent-fuel problems

The plutonium in spent fuel is the proliferation concern at the back end of the fuel cycle. A standard 1-GWe reactor produces roughly 200 kg of plutonium per year, enough in principle for about 20 weapons. This material is called reactor-grade plutonium, to contrast it with weapons-grade plutonium. The difference is in the amount of isotopes of plutonium (Pu) other than the weapon maker's favorite, Pu-239. Weapons-grade is about 95% Pu-239, whereas reactor-grade is about 50% Pu-239. Mixtures with considerably less Pu-239 than weapons-grade can in principle be made into a weapon, but they generate much radiation and heat, making weapons harder to build reliably. The fraction of this "bad" plutonium depends on how long the original fuel stays in the reactor—three years for reactor-grade plutonium but no more than three to four months for weapons-grade. No one has used reactor-grade material as a source of weapons, and the feasibility of making a weapon from it is still being reviewed by experts. For now, it is best to assume that it can be used and that the material is a proliferation risk.

When spent fuel comes out of a reactor, the radiation is so intense that some form of cooling is required to keep the fuel rods from damage that would result in the escape of radioactive material. The rods are put in cooling ponds where water keeps their temperature at a safe level. Typically, the rods stay in the ponds for at least four years. By then, the radioactivity and the associated heat generated have decayed enough to allow the rods to be removed from the ponds and put into dry casks for storage or shipping offsite. From this point, practices diverge.

Until recently, the United States supported a "once-through" fuel cycle in which the spent fuel is kept intact, with plans to eventually ship it to a geological repository for permanent entombment. The intense radiation from the fission fragments in the spent fuel forms a natural barrier to theft or diversion. Any potential thief would receive a disabling and lethal radiation dose in a matter of minutes.

Other countries have pursued another approach. France, which has the most well-thought-out and developed program, is an example. It reprocesses the spent fuel to extract the plutonium, mixes it with unenriched uranium to make a new fuel called MOX (mixed oxide), and uses this to generate 30% more energy in its power reactors from the original enriched-uranium fuel. The extraction process, called PUREX, is well known. After the MOX fuel is used and comes out of the reactor, it is stored with its radiation barrier intact for later use in a new kind of reactor that many believe will come into use in the second half of this century, when supplies of natural uranium may begin to run short.

The proliferation risk is that during one stage of reprocessing, pure separated plutonium (reactor-grade) is produced that might be vulnerable to theft (perhaps by terrorists) or diversion (by states intent on building nuclear weapons). Radiation from the separated plutonium is weak and thus is not a barrier to handling the material. Even when fabricated into MOX, the chemical separation of the plutonium and uranium is a simpler process than PUREX itself.

The proliferation risks involving spent fuel are different for the first four years and thereafter. Spent fuel must remain at its place of origin until its radioactivity has decayed sufficiently, but once the fuel is accessible, countries can use the "supreme national interest" clause in the Nuclear Non-Proliferation Treaty (NPT) to withdraw from the treaty, expel IAEA inspectors, and reprocess the fuel to produce plutonium for a weapon. This so-called "breakout" scenario, in which a country abides by the rules until it is ready to make weapons and then does what it wants, is the route North Korea took in developing its nuclear weapons. Although the spent fuel from North Korea's Yongbyon reactor had been around for a long time, the same situation would have been possible if the reactor had been continuously active, because there would have been sufficient spent fuel on hand.

Older spent fuel can be stored at the reactor site, stored offsite, or shipped out of the country to some international site. Shipping the material out of the country for nonproliferation purposes is favored by many, but it would not make much of a difference to determined proliferators. A country with a power reactor would have enough material in the cooling pond to make quite an arsenal. Even reactors with outputs of only 100 MWe would have enough material for about 10 weapons from the four years of stored fuel. Technical means can keep track of the spent fuel so that breakout intentions can be identified as early as possible, but no technical system can prevent it. This is why the potential hole in the back end of the fuel cycle is more difficult to plug than that in the front end.

The case in which shipping spent fuel out of the country does make a difference is in reducing the spread of reprocessing technology. Although the PUREX process is well known, the technology for implementing it is difficult to master. If reprocessing and the use of MOX fuel for energy purposes are to be broadly done, it would be best if the reprocessing plants were few, internationally owned and operated, and under tight surveillance (an approach known as advanced technical safeguards, in IAEA parlance). The French reprocessing plant at Le Hague already does reprocessing for other countries. Current practice is to send the MOX and the radioactive leftovers back to the country of origin.

The U.S.-proposed GNEP program is an interesting idea that would go even further. Fuel is leased, not sold; delivered just in time to the reactor owner; and spent fuel is returned to the lessor. In this scheme, both ends of the fuel cycle are handled by a small group of countries, mainly the nuclear weapons states in the original proposal. The front-end issues are the same as in the IAEA proposed system: security of supply. At the back end, GNEP proposes that the lessors separate the plutonium and other actinides and use this material themselves as fuel in a new kind of "burner" reactor. The lessors get electric power from the burner reactors, and the incentives for the lessee are being spared the burden and cost of enrichment and reducing the cost of disposing of the remaining radioactive waste. Burning the plutonium and other long-lived material reduces the required isolation time for the remaining waste, making it easier and less costly to isolate. When examined closely, GNEP adds an element to reducing the risk from the back end of the fuel cycle: limiting who uses plutonium-bearing fuel. It does

Martin Miller, *B-36 Strategic Bomber 1948 with Mk-17 H Bomb*,
Archival pigment print, 40 x 50 inches, 2007.

nothing, however, to limit the breakout potential from fuel still in the cooling ponds.

The first steps in securing the back end are clear, though imperfect. There should be a few internationally owned and operated reprocessing facilities. MOX fuel should be fabricated at the reprocessing facility, so that plutonium is not shipped around. Delivery to customers should be just-in-time for loading in the reactor where it is to be used. Cooling ponds and spent-fuel storage facilities should have more advanced technical monitoring systems installed. It would be desirable if spent fuel were shipped to international storage facilities, but there is no need to wait for that before starting down the road to greater security.

Don't wait for utopia

Scientists and engineers know that a major strengthening of the defenses against proliferation is a political issue, not a technical one. The politicians hope that some technical miracle will solve the problem so that they will not have to deal with political complications. Short of a distant utopia, the best step that the nations of the world can take is to make it difficult to move from peaceful uses to weapons, to detect such activities as early as possible, and to apply appropriate sanctions when all else fails. Although there are technical improvements that can reduce proliferation risk, it is only in the political arena that real risk reduction can occur.

Article IV of the NPT gives every signatory the right to develop nuclear technology for peaceful uses. The enrichment technology required for the production of reactor fuel is the same technology that can produce the highly enriched uranium required for a weapon. The reprocessing technology required to produce MOX fuel is the same technology required to secure plutonium for a weapon. Article X of the NPT lets a signatory go to the brink, withdraw from the treaty, and go nuclear if it so desires. Breakout potential is built into the current system

Today the talk is of somehow internationalizing the fuel cycle. Internationalization of both ends of the fuel cycle can reduce proliferation risk. Reduction is particularly needed at the front end, and a well-designed fuel supply system can allow big reductions in proliferation risk. The key, however, is ensuring political and commercial diversity in the supply chain, so that those who build their own reactors are not tempted to build their own supply chain as well. This is particularly important for those countries that pose the greatest risk: countries that are starting down the nuclear power road and have concerns about the reliability of a Western-dominated supply chain. Because enrichment and reprocessing plants are expensive and are uneconomical for smaller-scale programs, this is the kind of carrot that might make such programs more acceptable. A country that agrees to join receives an economic benefit that is preferable to going it alone. The core issue is to ensure a secure fuel supply to those agreeing to forego their own fuel cycle development.

Until the discussions meaningfully include the nations who are considering turning to nuclear power, they will not get anywhere. To achieve political diversity, China should be encouraged to enter into the commercial enrichment business; and to achieve commercial diversity, some other countries should be encouraged to develop internationally owned and operated enrichment and reprocessing services under appropriate safeguards. It might help if the United States set an example by encouraging the owners of the USEC to sell a share to the Canadians and others and to have their new partners share operations.

The real issue is the credibility of sanctions that can be imposed on those who violate the rules and start down the road to a nuclear weapons program. There is no technical barrier to proliferators, and if the international community does not act together, no program can succeed.

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