CHAPTER 16
NUCLEAR FUEL CYCLE

Anatoly Dyakov

It is now quite clearly understood that the greatest risk to the nuclear nonproliferation regime is the proliferation of the methods used to produce fissile nuclear materials. As the example of North Korea has demonstrated convincingly, a country that has access to the technologies of uranium enrichment and/or spent nuclear fuel reprocessing could potentially develop a nuclear weapon quickly, even while being a party to the Nuclear Non-Proliferation Treaty (NPT) and having its facilities under IAEA safeguard. Speaking figuratively, former IAEA director general M. ElBaradei has called the nuclear fuel cycle the "Achilles' heel" of the nonproliferation regime.[1]

The very presence of a breach in the nonproliferation regime as serious as the development of the NFC [nuclear fuel cycle], which some consider to be a loophole in the nonproliferation regime, naturally prompts questions about both the extent to which the NPT is meeting the goals of nonproliferation and its ability to adequately protect international security from new threats that may arise. Under current conditions, when the main threat is seen as being related to nuclear terrorism or to efforts by certain countries to acquire nuclear weapons, a top-to-bottom review and fundamental adaptation of NPT mechanisms and regimes will be required, as well as a detailization of the implications behind some of its requirements (particularly those concerning the scope of IAEA safeguards, the framework for peaceful nuclear cooperation under Articles III and IV, the procedures for withdrawing from the Treaty under Article X, the export control regime, and other measures). In this context, the nuclear fuel cycle will remain one of the more challenging issues.

Concerns about the sharp rise in oil and natural gas prices and shortages of fossil fuel reserves have led many countries in the world, including developing countries, to turn to nuclear power in order to satisfy their energy needs. Preservation of the international nuclear nonproliferation regime will require that solutions be sought that on the one hand would prevent the proliferation of sensitive nuclear technologies, and that on the other would provide newcomer countries with the assurance of a supply of nuclear fuel and services.

The Outlook For Development of the Nuclear Power Sector

World demand for electric power is predicted to double over its 2007 figure and perhaps reach 22,000 GWhr by 2030.[2] To meet this growing demand for energy, many countries have been reconsidering the role of nuclear energy as an alternative means for power generation. The reasons for this increasing interest in nuclear power generation can be traced to finite reserves of fossil fuel, the need to cut pollutant emissions that can lead to climate change, and considerable improvements in nuclear reactor technology. In the years since the Chernobyl nuclear disaster, nuclear power plants have improved significantly in both reliability and efficiency. For example, while the capacity factor for most nuclear power plants in the 1970s had been on the order of 50 percent, today it is about 90 percent. Recent improvements have increased the installed capacity of current reactors by 20 percent, while extending their service lives to 60 or 70 years.

There are currently 438 power generation reactors with a total installed capacity of 372 GW(e) operating in the world and another 55 reactors under construction.[3] According to IAEA forecasts, global nuclear power plant use could conservatively reach 473 GW(e) by 2030, or optimistically 748 GW(e).[4] A Massachusetts Institute of Technology (United States) study presents an even more optimistic scenario for the development of nuclear power generation. The authors of this report estimate that some 60 nations will have acquired nuclear power generation capabilities by the year 2050, with a total installed capacity approaching 1,500 GW(e).[5]

Nuclear power generation is currently being developed with particular rapidity in the Southeast Asia and Pacific regions: China, India, Japan, and South Korea have developed and are implementing truly large-scale nuclear power generation development programs. It should be noted that of the 17 reactors commissioned over the past five years, 12 were built in Asia, and that 28 of the 37 reactors currently under construction are also located in this region.[6]

Other nations in the region (Indonesia, Malaysia, the Philippines, Thailand, and Vietnam) have also expressed an interest in acquiring nuclear power.

Some countries in Europe and the Near and Middle East have also declared their intention to develop a nuclear power generation capability. Construction plans for nuclear power generation reactors have been approved for Bangladesh, Belarus, Turkey, and the United Arab Emirates, while Algeria, Bahrain, Egypt, Israel, Kazakhstan, Kuwait, Libya, Morocco, Oman, Poland, Saudi Arabia, Tunisia, and other countries have announced plans to pursue nuclear power generation.[7] According to IAEA director general Yukiya Amano, the number of countries using nuclear power to generate electricity could grow by an additional 10 to 25 by 2030,[8] although how quickly or broadly this process will proceed is difficult to predict. Still, the growth in the number of nations turning to nuclear power generation is cause for a certain amount of concern, primarily with respect to the potential risk that this represents for the nuclear nonproliferation regime, primarily with respect to the proliferation of sensitive nuclear fuel cycle technology, such as the enrichment of natural uranium and reprocessing of spent nuclear fuel.

The Nuclear Fuel Cycle

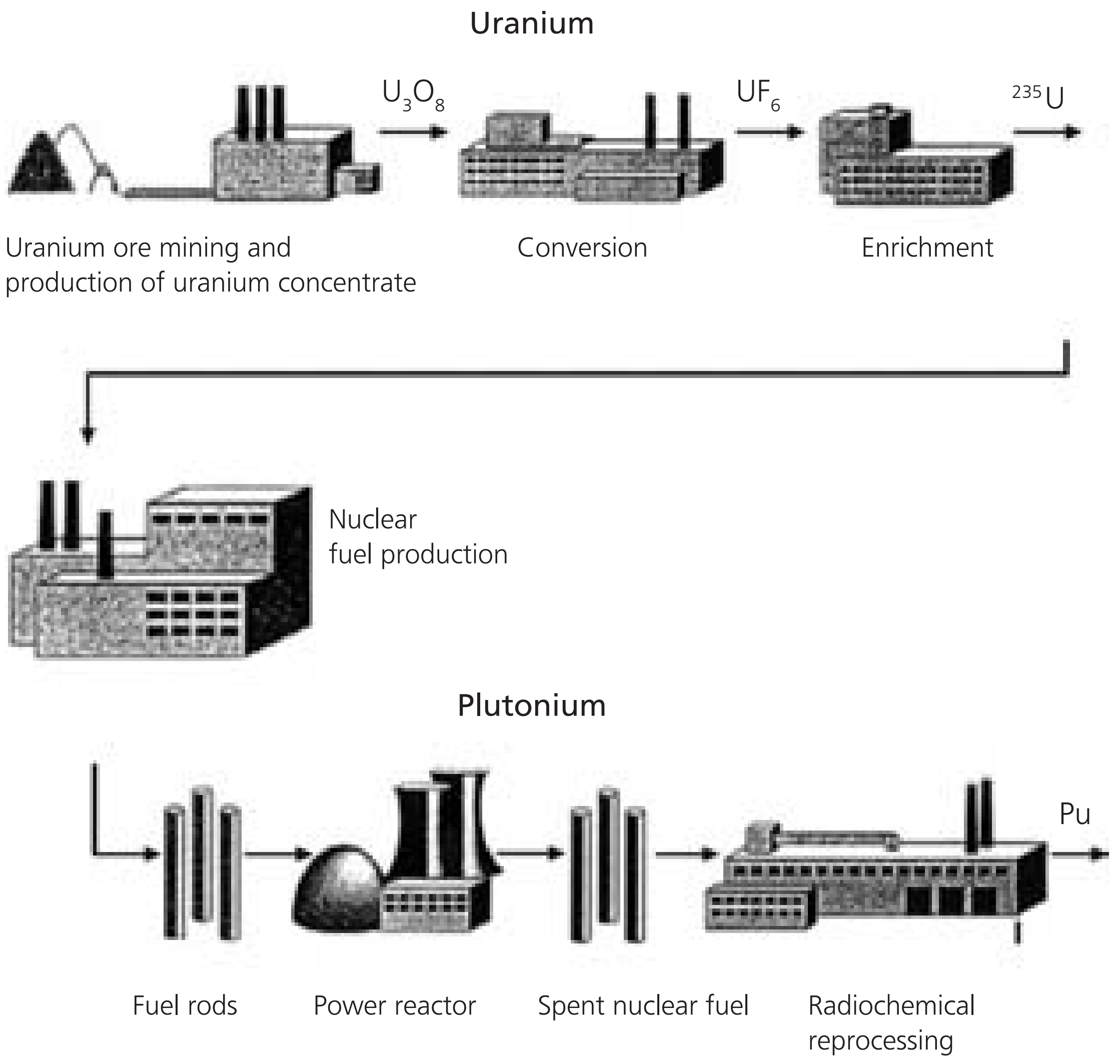
Most modern power-generating reactors use fuel in which the primary component is U-235, which can support a chain reaction. Aside from uranium fuel, a number of European nations (such as France) also produce and use converted MOX fuels having plutonium as the fissile material.

Natural uranium contains about 0.7 percent U-235 (the uranium isotope with a mass number of 235), with the remaining 99.3 percent consisting of U-238. Of these two isotopes, only U-235 can support a fission chain reaction that results in a release of energy. Natural uranium cannot sustain an explosive fissile chain reaction, and thus it cannot be used to produce weapons. However, once uranium has been enriched to more than 20 percent U-235, the IAEA defines it as a “direct use” material that could be used to create a relatively compact explosive device. Uranium that has been enriched to beyond 90 percent U-235 is classified as “weapons-grade” material and can be used in nuclear weapons. To enrich uranium beyond the natural level of U-235 requires quite sophisticated isotope separation technology.

Plutonium is an artificial element that does not occur naturally. It is produced when a U-238 nucleus captures a neutron, initiating a decay chain through the short-lived U-239 and Np-239 isotopes to Pu-239. The most appropriate device for producing plutonium is a nuclear reactor operating on either natural or low-enriched uranium. As the reactor operates, the process described above leads to an accumulation of plutonium in the fuel that can be recovered through chemical reprocessing of the spent nuclear fuel.

The NFC is customarily divided into two stages: the beginning (front-end) and the end (back-end). Figure 1 shows the main elements in the uranium and plutonium fuel cycles and indicates the stages where weapons-grade nuclear materials (U-235 and Pu) could appear.

Figure 1. The Main Components of the Nuclear Fuel Cycle



The front-end stage of the NFC begins with the mining of uranium ore and production of U_3O_8 concentrate. This uranium concentrate is then shipped to a conversion facility where the U_3O_8 is converted into uranium hexafluoride (UF_6), which is solid at room temperature but becomes a gas at 57^0 C. The UF_6 is then shipped to enrichment facilities to increase the concentration of the U-235 isotope. The product of this enrichment process is then sent to a facility that converts it into uranium oxide (UO_2), used in the production of nuclear fuel. As a rule, the degree of enrichment for fuel used in commercial power generation reactors is 4-4.5 percent.

The spent nuclear fuel contains mostly uranium enriched to about 1 percent, plutonium, and other decay products. One ton of spent nuclear fuel contains about five to eight kilograms of plutonium. The back-end stage of the NFC includes a process of cooling the spent fuel in ponds of water to lower its temperature. After three to five years of storage in the ponds (depending on the treatment procedure used), the fuel is either subjected to radiochemical reprocessing or placed into permanent storage. This reprocessing produces uranium, plutonium, and highly radioactive nuclear waste. The waste products are designated for final disposal, while the uranium and plutonium can be recycled into the production of nuclear fuel.

It is important to note that the front-end stages of the uranium fuel cycle are precisely the same as those used for manufacturing weapons-grade uranium. However, not all stages of the NFC are equally critical to the nonproliferation regime: most sensitive are the enrichment and reprocessing of spent nuclear fuel.

There are currently two enrichment technologies used in industrial facilities: gas diffusion (GD) and isotope separation using gas centrifuges (GC). Isotope separation is measured in “separation work units” (SWU). The efficiency of the various technologies and the capacities of uranium enrichment facilities are measured in SWU/year. It takes about 200 SWU to produce one kilogram of weapons-grade uranium, for example, but only seven to eight SWU to enrich one kilogram of uranium to 4 percent for commercial power reactor fuel.

The countries with uranium enrichment facilities are listed in Table 2.[9]

Table 2.
Countries With Uranium Enrichment Facilities

Country	Enrichment Method	Capacity (thousand SWU per year)
Brazil	GC (under construction)	120
China	GC	250
France	GC (under construction)	7500
Germany	GC	4500
Great Britain	GC	4000
India	GC	
Iran	GC (under construction)	100-250
Japan	GC	1050
The Netherlands	GC	3500
Pakistan	GC	170
Russia	GC	~30,000
The United States	Laser (under construction)	3500-6000
	GC (under construction)	6500-9500

Note: The British, Dutch, and German enrichment enterprises are owned by the global URENCO Enrichment Company.

Although the use of gas centrifuges has proven to be the more economical method of uranium enrichment and has come to dominate the industry today, it must be noted that certain technical characteristics of centrifuge technology also create the greatest threat to the nonproliferation regime. First, this method has a high stage separation factor (1.3-1.7) and UF_6 moves through the enrichment cascade quite rapidly. Only about 15 enrichment cycles are needed to produce fuel-grade uranium, while it takes about 40 cycles to enrich uranium to weapons grade. As a result, it takes only a short time (a matter of days) to reconfigure the centrifuge cascade from the production of low-enriched to that of weapons-grade uranium. This in turn makes the NPT “breakout” scenario possible, where civil technology is rapidly transformed to military use. Second, clandestine centrifugal enrichment facilities are difficult to detect, yet even a small-sized plant could produce enough highly-enriched uranium to make one or two nuclear explosive devices per year. The amount of electric power required for the enrichment (about

50 kWh/SWU) is comparable to the amount needed for lighting the plant where the enrichment takes place.

The reprocessing of spent nuclear fuel also represents a serious threat to the nonproliferation regime, since it results in the separation of plutonium. Spent uranium nuclear fuel from any type of reactor will contain a certain amount of plutonium. However, due to the fuel's high radioactivity, its plutonium remains quite unavailable unless and until it has been embedded in the spent fuel. From a technical standpoint, the process of fuel reprocessing is no secret and has been described in some detail in the literature. At the same time, the practical implementation of spent fuel reprocessing necessarily implies that reliable radiation shielding and remote manipulation systems also be developed, which results in significant expenditures. Additionally, it is more difficult to conceal the chemical reprocessing of spent nuclear fuel, since it is associated with the production of radioactive krypton-85, an easily detectable gas: "wisps" of radioactive krypton gas can be detected in the atmosphere up to several hundred kilometers away from the spent nuclear fuel processing facility.

Security Measures For the Nuclear Fuel Cycle

Obviously, in light of the anticipated widespread use of nuclear power, preservation of the nuclear nonproliferation regime will require countering the proliferation of sensitive nuclear technology on the one hand, while ensuring a guarantee of access to peaceful nuclear power for interested countries on the other.

At present, the civil nuclear power generation sector relies primarily upon the use of light water reactors, which account for 88 percent of installed capacity. Reactors of this type use low-enriched uranium fuel. One radical solution might be to switch to innovative nuclear power technologies that could sustain the nonproliferation regime based upon intrinsic physical and technological properties. This would require the development of new types of power reactors and fuel cycles. Work along these lines has already begun under a number of international projects, including Generation IV, the International Project in Innovative Nuclear Reactors and Fuel Cycles (INPRO), and GNEP+ANFC. However, even if the creation and use of such innovative nuclear technologies could be counted on, it would only be for the distant future. Over the next few decades, nuclear power generation will continue to expand based exclusively on the use of light water reactors and existing fuel cycle technologies. Thus, a solution to the nonproliferation problems caused by the potential increase in the number of nations using nuclear power should be sought through the implementation of new institutional, economic, and political barriers. All of these measures, while not creating obstacles to the development and use of nuclear power by newcomer countries, would induce them to voluntarily renounce acquisition of NFC technologies.

Countries are usually motivated to pursue NFC technology for the following reasons:

- to improve national security and enhance national prestige by gaining a nuclear weapons potential;
- to ensure national energy independence and security;
- to gain economic benefit.

Brazil and Iran, for example, could be considered to have been developing NFC technology primarily for the first and second of these reasons. At the same time, both motives could apply in one combination or another, or the second could officially be used to conceal the first.

The argument of economic benefit as justification usually appears rather dubious. The cost of nuclear fuel (including the price of uranium and cost of uranium enrichment) comprises only a small fraction of the costs of the electricity produced by a reactor. Even a tenfold increase in the price of natural uranium (from 30 to 300 dollars per kilogram) would result in no more than a 20 percent increase in the cost per kilowatt hour.[10] Similarly, a doubling of the price per SWU would increase the cost of a single kilowatt hour by only a few percent.[11] Thus, the argument in favor of acquiring enrichment technology for the economic benefit remains unconvincing. Whether or not such enrichment plants are being developed to export their products (where the economic benefits would be tied to global market conditions) is a different question.

On the other hand, the energy security argument for acquiring NFC technology is very convincing, requiring that global market capabilities be studied to guarantee that the entire range of civil NFC products and services be reliably provided, above all those relating to deliveries of uranium and the provision of enrichment services. Without such guarantees, no nation (particularly if it is considered a "problem" country) could be expected to abandon the idea of acquiring its own enrichment facilities.

Current annual global demand for natural uranium (U_3O_8) to fuel all 438 reactors comprises approximately 81,000 tons, while the amount being mined is just over 56,000 tons.[12] The difference between demand and production is covered primarily by previously acquired reserves. In the future, however, in light of the predicted growth in the nuclear power sector to a level of 680 GW, annual uranium mining will need to reach a level of at least 120,000 tons, which implies a substantial increase over current mining capacities (currently at a level of about 60,000 tons). Considering that proven natural uranium reserves that will cost no more than 130 dollars per kilogram to mine amount to 4.7 million tons, the demand for natural uranium under this development scenario for nuclear power generation should easily be satisfied for many decades to come.

Global demand for enrichment services in 2009 was 42 million separation work units.[13] Under the conservative development scenario for nuclear power generation (680 GW by 2030), annual demand for such services could be expected to reach about 82 million SWU, assuming the operation of only light water reactors. The global market in uranium enrichment services is currently dominated by four main players (EURODIF, TENEX URENCO, and USEC), which combine to supply 95 percent of the total global demand.

The U.S. company USEC has used the gaseous diffusion technology for uranium enrichment for many years. Its two plants in Poducah and Portsmouth are capable of producing 18.4 million SWU per year. However, the Portsmouth plant is currently idle and is not likely to resume operation. The gaseous diffusion method consumes dozens of times more energy than centrifugal enrichment, which makes it far less economical.[14] Four new enrichment plants are planned for construction in the United States, three of which will be based upon the gas centrifuge method and one on laser enrichment. A new plant planned for Piketon, Ohio, will produce 3.5 million SWU per year using recently developed U.S. centrifuge technology. The enrichment facility at Eunice, New Mexico, will use URENCO centrifuges to produce three million SWU per year. The AREVA company is planning the construction of a three million SWU per year plant in Eagle Rock, Idaho, using URENCO technology. In Wilmington, North Carolina, the Global Laser Enrichment company is teaming up with General Electric Hitachi and Cameco to build a three million

SWU per year enrichment plant using Silex laser technology developed in Australia.[15]

The multinational company EURODIF, a member of the French AREVA group that also includes partners from Belgium, Iran, Italy, and Spain, operates the Georges Besse gaseous diffusion plant in Tricastin, France, with a production capacity of up to 10.8 million SWU/year. Although the nations participating in this company enjoy guaranteed access to enrichment services, France alone retains ownership of the enrichment technology. The gaseous diffusion technology used at Georges Besse is currently being replaced with centrifuge technology. The modernized plant will have an installed capacity of 7.5 million SWU per year, which can be increased to 11 million SWU per year if necessary.[16] The first centrifuge line at the plant was commissioned in December 2009, with the facility expected to begin full production in 2016.[17]

The multinational URENCO company (Germany, Great Britain, and the Netherlands) also employs centrifuge technology for uranium enrichment. The company's three plants are planned to reach a total capacity of 12 million SWU per year by the end of 2012.[18]

The Russian TENEX company has four enrichment plants using sixth-, seventh-, and eighth-generation gas centrifuges to produce a total of about 24 million SWU. Under the recently adopted Russian enrichment modernization program, older-generation centrifuges are being replaced with more recent models, and total annual production is expected to reach 28.8 million SWU by the end of 2010.[19]

It must be said that from the very inception of the nuclear power sector, the uranium and uranium fuel market has maintained extremely high supply security standards, with not a single instance of a power generation reactor shutting down due to an interruption in the fuel supply. Global uranium enrichment capacities will continue to exceed demand for the foreseeable future. Considering the dynamism and potential capabilities of the uranium enrichment market, it can be assumed that it will be economically and technologically capable of continuing to satisfy any rise in future demand for these services under any development scenario.

The risk does remain, however, that some consumers will be unable to obtain nuclear fuel cycle services on the market, primarily for political reasons. Thus, conditions would need to be established so that any consumer who strictly observes all nuclear nonproliferation commitments would be granted convincing guarantees of NFC services.

Former IAEA director general M. ElBaradei believes that this could be accomplished by developing and establishing a multilateral nuclear fuel cycle mechanism.[20] Such a mechanism would neither undermine national sovereign rights to the peaceful use of nuclear energy nor create yet another discriminatory barrier between those who "can" and those who "cannot" have NFC technology, yet it would provide a way to guarantee the provision of NFC services on a non-discriminatory basis and be an effective incentive for nations to refrain from acquiring such technology on their own.

Guaranteed Nuclear Fuel Cycle Services

Experts at the World Nuclear Association believe that the creation of such a mechanism would require the development and implementation of a range of measures aimed both at bolstering the current NFC services market and ensuring that cost-effective services are provided to any nation that uses nuclear energy and has renounced the acquisition of sensitive technology.[21] This initiative was introduced following the disclosure in 2003 of the existence of a secret network that had been created by Pakistani nuclear scientist A.Q. Khan for the export of nuclear technology and equipment.

In a speech before the session of the United Nations General Assembly on November 3, 2003, the director general of the IAEA suggested that the world consider restricting uranium enrichment and fuel processing exclusively to facilities under multinational control.[22] In 2004 he established a group of international experts to consider possible approaches and incentives to attract states to create a multilateral NFC. In its report, this group proposed the following:

- to guarantee the supply of fuel to nuclear power generating reactors;
- to convert existing national NFC facilities to multinational facilities;
- to create multinational regional NFC facilities under joint ownership.[23]

At the same time, the report noted that there were no provisions under international law to require countries to join a supply assurance program of this kind.

Between 2004 and 2007, there were over a dozen initiatives advanced by various countries and organizations aimed at preventing the proliferation of sensitive NFC technology, all of which suggested primarily that nuclear fuel supplies be guaranteed and that international NFC service centers be established.[24]

The initiatives of U.S. President George W. Bush. In order to close the loophole in the Nuclear Non-Proliferation Treaty that allowed countries to acquire NFC technology legally, in 2004 the U.S. president appealed to the countries belonging to the Nuclear Suppliers Group to refrain from providing uranium enrichment or spent nuclear fuel reprocessing technologies to any country that currently lacks operational enrichment or processing facilities of its own, and to ensure reliable access to nuclear fuel at a "fair" price to those countries that have agreed to refrain from acquiring such technology.[25] This initiative, however, failed to gain support, since it suggested creating yet another level of discriminatory division of NPT members (in addition to the existing one) into "legally" nuclear nations and non-nuclear nations. The main question remained unanswered: which countries would be allowed to have the NFC, and which would not? In the final result, President Bush's initiative worked not so much to enhance the NPT as to weaken it. As the example of Iran has shown, another division of nations into those that are permitted to have enrichment and reprocessing capabilities and those that are not would work against achieving unity among the member nations and would stimulate the development of a "nuclear black market."

In February 2006, President Bush proposed a more in-depth initiative on preventing proliferation called the Global Nuclear Energy Partnership (GNEP), which proposed using new types of nuclear reactors and further improvements to the NFC to develop the civil nuclear power sector and suggested establishing an international consortium of nations that possess enrichment and processing technology (China, France, Great Britain, Japan, Russia, and the United States), which would refuse to provide or transfer processing technology to other countries while offering guaranteed fuel cycle services, including the lease of fresh nuclear fuel and the return of spent fuel, to any counties that would forego development of their own enrichment and reprocessing technologies.

However, due to the complexity of the program, doubts in its ability to address matters of nuclear technology nonproliferation, and criticism of the program by experts outside the government who were particularly troubled by its domestic spent nuclear fuel component, the U.S. government was forced to abandon the idea of implementing these measures within the country.[26] The international aspect of the program is currently under review. It appears that the United States would like to retain it, but structure it differently and give it a new name.

The initiatives of Russian President Vladimir Putin. In January 2006, Russian President Vladimir Putin proposed creating an international center under joint ownership with other countries in order to provide nuclear fuel cycle services (including uranium enrichment) on a non-discriminatory basis and under the control of the IAEA.[27] Under this initiative, Russia announced the establishment of the International Uranium Enrichment Center (IUEC), where any nation that sought to develop peaceful nuclear power but not to acquire sensitive technology would be entitled to conclude an intergovernmental agreement with Russia to become a full co-owner (i.e., shareholder) of the IUEC. One of the key principles of the operation of this center would be the fact that its production facilities remain under IAEA safeguard, while the option of IAEA participation in the management of the center is left open. IUEC co-owners would be guaranteed the following:

- supply of low-enriched uranium or provision of enrichment services;
- participation in management of the IUEC;
- access to all information on prices and contract terms and confidence in their fairness;
- a share of the revenues from this quite profitable business.

Only the actual enrichment technology itself would remain unavailable to the foreign co-owners.

The Russian IUEC initiative has essentially entered the implementation stage. With conclusion of an intergovernmental agreement between Russia and Kazakhstan, the process of establishing the IUEC at an existing enrichment facility in the city of Angarsk (Irkutsk Oblast) was nearly complete, and the Center has since begun operation.[28] Armenia signed on to activities at the Center in February 2008,[29] and a number of other countries, including India, Japan, Mongolia, South Korea, and Ukraine, have also expressed an interest in participating in the IUEC.[30]

Other initiatives. In June 2006, six nations with their own enrichment activities (France, Germany, Great Britain, the Netherlands, Russia, and the United States) proposed a "Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel," under which guaranteed supplies of low-enriched uranium for nuclear fuel would be offered to those nations that have foregone creating their own national enrichment facilities and signed comprehensive safeguards agreements with the IAEA, including the 1997 Additional Protocol. The idea behind this project was that if a situation should arise under which one of the six nations would be unable to meet its LEU delivery obligations, the other five nations would make the shipments in its place, provided that the IAEA has confirmed that the nation has met all of its nonproliferation obligations. The implementation of this initiative assumes that a multi-tiered system of safeguards would be established that would include backup provisions in standard contracts and would establish LEU stockpiles under IAEA control. In September 2006, Japan proposed the IAEA Standby Arrangement System to supplement the Six Country Project and serve as an early warning system to avoid disruptions to nuclear fuel supplies. Finally, in September 2006, the United Kingdom proposed implementing an "enrichment bond" concept to provide greater assurances to the nations seeking nuclear fuel cycle services.

In September 2006, the Nuclear Threat Initiative (a U.S. nongovernmental organization) announced that it would contribute 50 million dollars as seed money to help create an LEU stockpile owned and managed by the IAEA.[31] The Agency would manage this stockpile in order to guarantee non-discriminatory and non-political fuel supplies to the nations that have renounced enrichment activities. However, the use of the NTI money would be conditional on the requirement that one or more IAEA members would contribute an additional 100 million dollars in funding. This circumstance, as well as the lack of resolution of some other unresolved issues (such as the degree of LEU enrichment, storage locations, the production of fuel from the stockpile for specific client nations, and the price) have made this proposal difficult to implement.

Russia has also supported the initiative to establish a nuclear fuel bank. Speaking at the 51st IAEA General Conference, Sergey Kirienko, director general of the Russian Federal Atomic Energy Agency (Rosatom), announced Russia's intention to create a low-enriched fuel stockpile at the Angarsk IUEC. The IAEA Board of Governors supported this Russian initiative in a resolution passed on November 27, 2009. In late March 2010, an agreement was signed to establish a stockpile of low-enriched uranium within the borders of the Russian Federation.[32] It provided for the establishment of a guaranteed physical "rainy day" stockpile of 120 tons of LEU in the form of UF_6 enriched to between 2.0 and 4.95 percent to be stored at the IUEC under IAEA safeguards for the exclusive use of IAEA members in order to resolve problems in the event of an interruption in the supply of LEU. Russia will also bear the costs of applying the IAEA safeguards.

The internationalization of NFC services and unresolved issues. As noted above, international law currently does not require countries that purchase nuclear fuel to participate in international NFC centers. Moreover, as discussions surrounding the proposed initiatives at an IAEA seminar on the issue in September 2006 have made clear, the majority of nations would oppose any plan reinforcing their division into suppliers and consumers of nuclear fuel, seeing any attempt to create a system that is not perceived to be fair and aimed at universal rights as a creeping trend against the fundamentals of the NPT. The NPT contains no restriction on peaceful nuclear activity, including enrichment, and the countries of the third world have no intention of renouncing their right to do so. The prejudice against any attempt at internationalizing the nuclear fuel cycle was clearly evident during the IAEA vote on the Russian fuel bank proposal, when several third world countries voted against the measure or abstained.[33]

Consequently, the ultimate success of the proposed initiatives will be determined primarily by the nuclear fuel consumer nations through their choice to use the world market for NFC services rather than developing NFC capabilities of their own. Clearly, the only way to induce more nations to do the same would be by guaranteeing them reliable supplies of fuel at better prices.

The idea of creating an LEU and nuclear fuel bank under IAEA safeguards and at reduced cost for countries that have renounced the NFC would raise a number of problems. Although the fundamental idea may appear attractive and "brilliantly simple," the devil, as they say, is in the details. For example, who is to pay the cost of operating the uranium enrichment and fuel processing plants and at what price? If the nuclear materials are to be delivered to "reliable" clients at reduced cost, who would cover the difference between the market price and the discounted price while maintaining profitability and the ability to pay investor dividends? The IAEA budget lacks the funds to cover such expenditures, and the Agency is not authorized to conduct any commercial activity.

The establishment of international enrichment centers would also raise broader questions: what will happen to the nuclear materials market once these centers begin to supply LEU at essentially fixed cartel prices? What guarantees are there that this price would in fact be the lowest possible and thus be able to provide enough of an incentive to the fuel consuming nations to renounce their own NFC? Is there a way to ensure that a "guaranteed supply of LEU" would not be turned into an instrument for blackmailing the Agency by the consuming countries into gaining ever-greater discounts and preference in nuclear cooperation under Article IV of the NPT? After all, any country would theoretically lay claim to such preferential supply (and perhaps also for manufactured fuel) by declaring that it would otherwise begin developing its own nuclear fuel cycle.

The establishment of such multilateral NFC centers (MNFC) would also bring about a number of economic, technical, and legal difficulties. Would the right of a country to obtain LEU or nuclear fuel depend upon its share in the MNFC, or only upon its decision to renounce the NFC, with prices and amounts dependent upon global market conditions? In other words, if a country has decided not to contribute to the MNFC, would it still be eligible for guaranteed deliveries if it merely renounced a nuclear fuel cycle program of its own? What would the economic relationship be between the Center and the national uranium export companies, especially those belonging to countries that also participate in the MNFC abroad? Would this mean that the guaranteed LEU supplies from the future MNFC would displace those of the national uranium enrichment companies, leaving them to supply the markets of the NFC countries exclusively? How would losses to the MNFC companies that have resulted from guaranteeing the supply of LEU at discounted prices be offset? Which MNFC member countries would be responsible for returning spent nuclear fuel to their territories and reprocessing and storing it?

Moreover, by monopolizing two key areas of the NFC (uranium enrichment and spent nuclear fuel reprocessing), the MNFC could also negatively impact the markets for other stages of the NFC: the manufacture of uranium concentrate, uranium hexafluoride, and reactor fuel rods. This applies particularly to fuel rods, since the certified delivery of the fresh rods and the subsequent removal of spent rods for processing are both closely associated technically and economically to delivery of the reactors themselves.

Finally, the success of the initiative proposed by IAEA leadership for a progressive internationalization of the fuel cycle (implied by plans for expansion of the MNFC) would ultimately depend upon achieving progress in prohibiting the production of fissile material for military purposes. It could hardly be expected that all of the countries that lack NFC technology would agree to link their nuclear power industries to the MNFC for all time unless all of the other countries that have the technology to produce fissile materials (including the five nuclear members of the NPT and the four "outsiders") have formally agreed to prohibit the production of fissile materials for weapons, and while their enrichment plants and spent nuclear fuel reprocessing facilities remain beyond IAEA safeguards. This issue could potentially be resolved in principle through negotiations on the Fissile Material Cut-off Treaty (FMCT) at the Conference on Disarmament in Geneva, although these talks have long been deadlocked as a result of disagreements among the members over the military, strategic, technical, and political aspects of the Treaty.

All of these questions will require objective, detailed, and competent consideration, building on the experience gained through analysis of the subject conducted in the 1970s and 1980s. Current practical solutions to the various aspects of the problem of the nonproliferation of nuclear fuel cycle technology must also be evaluated. In this respect, the construction of a nuclear power plant in Iran by the Russian company Atomstroyexport is of particular interest. Under the intergovernmental agreement, Russia has assumed responsibility for providing the fresh fuel for the Bushehr plant and for removing the spent nuclear fuel. The extension of such practices to all countries that are beginning to develop nuclear power would be in line with the requirement for ensuring security of the NFC. A side benefit of this approach for the nuclear fuel consumer countries would be the fact that it would relieve them of the serious problem of dealing with spent nuclear fuel and would thus remove the main obstacle to their national nuclear power development programs. On the other hand, as the experience with Iran has shown, such bilateral agreements in themselves would not necessarily eliminate a nation's desire to develop its own nuclear fuel cycle.

It is no secret that the current interest in the fuel cycle problem is due primarily to the protracted crises surrounding the nuclear programs of Iran and North Korea. The precedent set when North Korea withdrew from the NPT and developed nuclear weapons using resources obtained during its cooperation with the IAEA has forced the international community to take an extremely critical view of the Iranian NFC program, which, moreover, is being carried out in violation of IAEA safeguards. However, the new NFC concepts are unlikely to seriously affect resolution of the problem that the nuclear programs of these two nations have created. These issues are now being addressed through multilateral negotiations, which are considering individual solutions for each case. The best that could be hoped for is that one approach or the other to guaranteed deliveries of LEU or finished fuel would be included as a component of such agreements. However, the issue of internationalizing the NFC must not be allowed to be forgotten, even should the Iranian and North Korean crises be resolved positively. Otherwise, a repeat of these difficulties and risks will become all but unavoidable.

On the whole, both extensive development of nuclear power generation and prevention of the proliferation of sensitive nuclear technologies through proliferation of the fuel cycle will be possible provided the following fundamental conditions are met:

- the members of the NPT must reach understanding on the need for renouncing the construction of any new national enrichment facilities, including those of low capacity;
- the countries that already possess enrichment technology must act to transition fully to MNFC over the long term;
- these efforts must be aimed both at strengthening the existing nuclear services market through long-term contracts with greater transparency, and at offering guaranteed and non-discriminatory NFC services to any NPT member nation that has abandoned domestic development of uranium enrichment or spent nuclear fuel reprocessing technology;
- aside from the price incentive system, a comprehensive system of technological and commercial compensation should be developed to offer the nations that have renounced the NFC;
- newcomers would receive assistance in developing their nuclear power generation sector from the nuclear technology supplier nations only after they have joined the 1997 Additional Protocol;
- the potential transition to MNFC under the auspices of the IAEA should be accompanied by expansion of the 1997 Additional Protocol to apply to the full civil nuclear infrastructure of the nuclear powers, and if the FMCT is concluded, to all their uranium enrichment and spent nuclear fuel reprocessing facilities as well.

NOTES

1 *Multilateral Approaches to the Nuclear Fuel Cycle: Report by the Expert Group Presented to the IAEA Director General*, April 28, 2005, INFCIRC/640.

2 *Report on Proliferation Implications of the Global Expansion of Civil Nuclear Power*. (International Security Advisory Board, Apr. 7, 2008); *International Energy Outlook 2006*, U.S. Department of Energy (Washington, D.C., June 2006), http://www.eia.doe.gov/oiaf/ieo/index/html.

3 http://www.iaea.or.at/programmes/a2/.

4 *International Status and Prospects of Nuclear Power: Report by the Director General,* Aug. 12, 2008, GOV/INF/2008/10-GC(52)/INF/6.

5 John Deutch, Ernst Moniz et al., *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge, Mass: MIT Press, 2003).

6 http://www/iaea/org/cgi-bin/db/page/pl/pris/reaucct.htm.

7 http://www.iaea.org/NewsCenter/News/2006/newcountries.html; *Nukem Market Report*, December 2006.

8 http://www.iaea.org/NewsCenter/Statements/2010/amsp2010n002.html.

9 International Panel on Fissile Material (IPFM), *Global Fissile Material Report 2008*, www.fissilematerials.org.

10 William C. Sailor and Erich Schneider, *Nuclear Fusion* (Los Alamos National Laboratory, Aug. 31, 2005).

11 Harold Feiveson, "Managing the Civilian Nuclear Fuel Cycle," *The Global Fissile Material Report 2007*, http://www.fissilematerials.org.

12 Paladin Energy Ltd., "The New Energy in the Market," (Platts 6th Annual Nuclear Energy conference: *Opportunities for Growth and Investments*, Feb. 17, 2010).

13 http://www.world-nuclear.org/info/default.aspx?id=452&terms=enrichment+capacity.

14 According to the company's website, URENCO centrifuges consume 50 kW/SWU of energy, compared to the 2,400 kW/SWU consumed by gaseous diffusion technology. http://urenco.com/sectionFrontPage.aspx?m=63.

15 http://www.world-nuclear.org/info/default.aspx?id=452&terms=enrichment+capacity.

16 "Georges Besse II, A New Era of Enrichment," http://www.eurodif.fr./servlet/.

17 http://www.world-nuclear.org/info/inf40.html.

18 International Panel on Fissile Material, *Global Fissile Material Report 2008*, www.fissilematerials.org.

19 *Russian Enrichment Industry. State & Prospects. Annual Report 2004*, http://www.ibr.ru.

20 Dr. Mohamed ElBaradei, IAEA Director General, *A New Framework for the Nuclear Fuel Cycle* (Statement at Special Event, Vienna, Austria, Sept. 19, 2006), http://www.iaea.org/about/policy/GC/GC50/Site Event/index.html.

21 "Ensuring Security of Supply in the International Fuel Cycle," (WNA Report, May 12, 2006), http://www.world-nuclear.org/reference/pdf/security/pdf.

22 Dr. Mohammed ElBaradei, IAEA Director General (Statement to the 58th Regular Session of the U.N. General Assembly, Nov. 3, 2003).

23 *Multilateral Approaches*.

24 Yury Yudin, *Multilateralization of the Nuclear Fuel Cycle: Assessing the Existing Proposals* (Geneva: UNIDIR, 2009).

25 The White House, *Strengthening International Efforts Against WMD Proliferation*, Fact Sheet, Feb. 11, 2004, http://www.whitehouse.gov/news/release/2004/02/20040211-5.html.

26 "The U.S. GNEP Initiative is Dead," *Nuclear News Agency*, April 16, 2009, http://atominfo.ru/news/air6332.htm.

27 V. Putin (Statement on the peaceful use of nuclear energy, St. Petersburg, Jan. 25, 2006), http://www.kremlin.ru/appears/2006/01/25/1624_type63374type63377_100662.shtml.

28 "The Head of Rosatom reports that the International Uranium Enrichment Center has been completed" (*RIA Novosti*, May 10, 2007).

29 "Armenia Will Enrich its Uranium in Russia's Angarsk," *Lenta ru*, Feb. 6, 2008, http://lenta.ru/news/2008/02/06/join/.

30 S.V. Kiriyenko, Head of Rosatom, interview by Rustam Arifdzhanov, *107 Minutes*, the Russian News Service, July 3, 2007, http://www.minatom.ru/News/Main/view?id=46483&idChannel=72.

31 International Atomic Energy Agency, "Nuclear Threat Initiative Commits $50 million to Create IAEA Nuclear Fuel Bank," press release, September 19, 2006, http://www.nti.org/c_press/release_IAEA_FuelBank_091906.pdf.

32 "Russia and the IAEA Sign an Agreement Setting Up a Guaranteed Low-Enriched Uranium Stockpile in Angarsk," http://www.nuclear.ru/rus/press/nuclear_cycle/2115971/.

33 The "no" votes came from Argentina, Brazil, Cuba, Egypt, Malaysia, Pakistan, South Africa, and Venezuela. India, Kenya, and Turkey abstained. http://www.atominfo.ru/news/air8549.htm.