Multinational Approaches to the Nuclear Fuel Cycle

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Cover image: Nuclear waste in storage: Cherenkov radiation from spent nuclear fuel causes a blue glow at a radioactive waste storage facility in France.
Photograph © Roger Ressmeyer/Corbis.

ISBN#: 0-87724-084-1

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Contents

Introduction

With the recent attention to new nuclear power, the challenge of managing the spread of nuclear technology has increased. At the same time, the growth of interest in nuclear power can serve as an important opportunity to improve the related safety, security, and nonproliferation regimes. One such opportunity arises in the context of the back-end of the nuclear fuel cycle, and the concern over how to mitigate the spread of enrichment and reprocessing, as well as how to store and ultimately dispose of spent nuclear fuel.

The first essay in this collection, "The Key Role of the Back-End in the Nuclear Fuel Cycle" by Charles McCombie and Thomas Isaacs, has been reprinted from the Winter 2010 issue of *Daedalus* on the global nuclear future. It focuses on the proliferation concerns that arise from enrichment and reprocessing as well as on the opportunities at the back-end of the fuel cycle for regional and international initiatives that may help to assuage energy, security, and waste concerns. Managing the emerging nuclear order will require the development of a clear set of goals, in which the issues surrounding the back-end of the fuel cycle must be included and satisfactorily addressed. This essay seeks to contribute to those efforts.

It is followed by four new papers whose authors were invited to reflect on this issue and to share their thoughts on this topic. These new papers reflect a diversity of sources and opinions, in keeping with both the global importance of these questions and the benefits of developing an international perspective on how they might be addressed. The authors focus on various aspects of the challenges raised by the back-end of the fuel cycle and offer possible options for addressing these challenges. This volume also includes an edited version of remarks made by Ellen Tauscher, Under Secretary of State for Arms Control and International Security, at a January 2010 conference at the Hoover Institution in Stanford, California. Under Secretary Tauscher's remarks underscore the shared sense of the importance of addressing the back-end of the fuel cycle, in government as well as within academic and other non-governmental circles.

This importance cannot be overstated when considering the growth of nuclear power. As Tariq Rauf observes in his essay, most of the spent fuel around the world is kept at the nuclear power plants that have generated it. All of the authors, however, support the idea of moving from the current status quo toward some form of multinational or international approach to dealing with spent fuel, including the possibility of the establishment of international spent-fuel repositories. Although Rauf notes the likelihood of strong public opposition to international repositories (based on the traditional resistance even to national repositories), Frank von Hippel observes that communities in Finland and Sweden that host nuclear power plants have actually volunteered to host underground repositories, suggesting that it may be possible for public opposition—even toward international repositories—eventually to be overcome.

Two of the authors (Frank von Hippel and Atsuyuki Suzuki) suggest that the United States should be the first to serve as a host for an international repository and take spent fuel from other countries with small programs, as a way both to strengthen the nonproliferation regime and to increase nuclear safety and security worldwide. Suzuki asserts that such an approach, by the United States, would serve as an "epoch-making opportunity for the [Obama] administration to take the leadership" on this issue.

The essays in this collection engage with the challenge of the back-end of the fuel cycle in very different ways, whether through a cross-comparison of the programs of Japan, the Republic of Korea, and Russia, or through a focus on the history and current role of international organizations in this area. All, however, are linked by a recognition that the back-end of the fuel cycle has often been overlooked in discussions of the anticipated nuclear renaissance. They also share a general support, in principle, for international approaches to the back-end of the fuel cycle, although, as Noramly Bin Muslim points out, such approaches "by no means constitute a 'magic bullet' that can solve nonproliferation problems."

This publication thus stands as the continuation of the conversation begun both by the special issues of *Daedalus* on the Global Nuclear Future and by a meeting sponsored by the Academy in Abu Dhabi on nuclear power in the Middle East. With a growing desire for development, and a reliable energy supply, comes the need for a global expansion in nuclear power. A serious discussion of all aspects of this expansion is necessary if it is to be managed safely and securely. We hope that the papers contained herein contribute to that discussion and help to build the basis for a more sustainable international nuclear order.

This Occasional Paper is part of the American Academy's Global Nuclear Future Initiative, which is guided by the Academy's Committee on International Security Studies. The Initiative examines the safety, security, and nonproliferation implications of the global spread of nuclear energy and is developing pragmatic recommendations for managing the emerging nuclear order. The Global Nuclear Future Initiative is supported by generous grants from Stephen D. Bechtel, Jr.; the S.D. Bechtel Foundation; the Carnegie Corporation of New York; the William and Flora Hewlett Foundation; the Alfred P. Sloan Foundation; the Flora Family Foundation; and the Kavli Foundation. We thank these funders for their support.

The Academy is grateful to the principal investigators of the Global Nuclear Future Initiative—Steven E. Miller, Scott D. Sagan, Robert Rosner, and Thomas Isaacs—along with expert members of the project's advisory committee—John W. Rowe, Richard A. Meserve, and Albert Carnesale—for contributing their time, experience, and expertise to the work of the Initiative. We would also like to thank the authors for bringing their knowledge and insight to bear on these important issues.

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CHAPTER 1

The Key Role of the Back-End in the Nuclear Fuel Cycle

Charles McCombie and Thomas Isaacs

The recent two-volume special issue of *Daedalus* on the Global Nuclear Future highlights the challenges associated with the global expansion of nuclear power.[1] The topics covered include environmental impacts, nuclear safety, and the economics of nuclear power production, but the major emphasis is on nonproliferation and security aspects. To develop an understanding of possible problems and their potential solutions in all of these areas, it is necessary to understand the nuclear fuel cycle. Controlling the flow of nuclear materials "from cradle to grave" creates and sustains a safe and secure global nuclear power regime that can help satisfy the world's energy needs and can reduce CO_2 emissions and their associated impacts on climate.

The nuclear fuel cycle consists of multiple technical activities that take place in locations around the world. These activities form a chain, with each having direct impacts on the characteristics of those farther down the line. Accordingly, one objective of this article is to emphasize the holistic and global nature of the fuel cycle. A key challenge to consider is whether there can be opportunities now or in the future to improve the safety, security, economics, environmental impacts, or public acceptance of nuclear power by vertical integration of the chain or by geographical consolidation of the activities.

Each stage of the fuel cycle should be assessed to judge where improvements could increase technical and societal acceptance of a substantial expansion of nuclear power. We concentrate, however, on the back-end stages—namely, storage, reprocessing, and disposal.

To examine the back-end stages of the fuel cycle, it is useful to begin with a brief summary of their current status.

Used fuel storage. All water-cooled reactors store spent nuclear fuel, once it has been unloaded from the reactor, at the reactor site in an underwater pool. Originally it was planned that spent fuel would be shipped off site after some years of cooling; the fuel would then go for reprocessing or direct disposal. In practice, reprocessing is currently carried out in only a few programs, and disposal of spent fuel has not yet taken place. The need for storage has thus increased.

1. This essay was first published in *Daedalus* 139 (1) (Winter 2010).

The cooling time before the heat generation of spent fuel has declined to a level suitable for disposal in a geological repository is between thirty and fifty years. There are also other arguments for delaying disposal. For small nuclear programs, many years of operation would be required to accumulate an inventory of spent fuel that justified embarking on an expensive deep repository project. Furthermore, by extending surface storage times for decades, the large expenditures required for implementing such a solution can be postponed.

Today, as pools at reactor sites fill up, spent fuel is increasingly placed in dry storage facilities, which have lower operational costs and which can be implemented in a modular fashion. The casks can be purchased as needed; they do not require a strengthened or strongly shielded building; and they can even be placed on pads in the open air. Most storage facilities are built above ground, although there are exceptions, such as the Swedish CLAB spent-fuel pool, situated in a rock cavern some tens of meters below the surface.

Reprocessing. In current reprocessing facilities, used fuel is separated into its three components: uranium and plutonium, which both can be recycled into fresh fuel, and waste containing fission products. The waste is then treated to produce vitrified blocks incorporating most of the highly radioactive materials and other low- and intermediate-level radioactive technological wastes. After conversion and enrichment, the uranium from reprocessing can be reused as fuel, if necessary. The plutonium can either be stored or made directly into mixed oxide (MOX) fuel, in which uranium and plutonium oxides are combined. The vitrified waste is a high-quality standardized product well suited for geological disposal. The technological waste is of much lower activity, and much of it can go to near-surface disposal sites. However, there are problems associated with each output stream.

Plutonium and MOX are unstable in storage because of the buildup of Am241. MOX fuel is more expensive than fresh UO_2 fuel; its specific decay heat is around twice that of UO_2 fuel; and the neutron dose from MOX is about eighty times that from UO_2 fuel. Reprocessed uranium is a "free" by-product, but with modern high burn-up levels, there is less residual U235 and more U236. Moreover, reenrichment increases U232 levels and presents a greater radiation hazard. The vitrified waste has a smaller volume than packaged spent fuel, but it still requires disposal in a deep geological repository, whose costs do not increase in proportion to the volume of the inventory. The parts of technological waste that contain long-lived radionuclides and must therefore go to geological disposal can present problems since the waste forms (cement, bitumen, compacted pieces) are less durable than vitrified waste or spent fuel.

The strongest argument in favor of reprocessing is that it saves resources, although the real benefits will be realized only when fast reactors are in use. A further positive aspect is that the highly active vitrified waste, in contrast to spent fuel, does not fall under International Atomic Energy Agency (IAEA) safeguards and presents no proliferation risk. However, the fact that current reprocessing technology involves separation of weapons-usable plutonium has led to concerns about the spread of the technology to many countries.

Disposal. Today, it is widely accepted in the technical community that the only presently feasible method to ensure very long term (many millennia) safety for high-level waste or spent nuclear fuel is isolation in a stable, deep geological repository. Nevertheless, at present there are no disposal facilities (as opposed to storage facilities) in operation in which used fuel or the waste from reprocessing can be placed.

For at least twenty-five years after the original 1950s publication on the concept of geological disposal, the validity of this approach was not questioned. It was formally adopted as a final goal, through policy or legal decisions, in many countries, including the United States, Canada, Sweden, Finland, Belgium, Switzerland, France, Spain, South Korea, the United Kingdom, and Japan. However, virtually every geological waste disposal program in the world encountered difficulties in keeping to originally proposed schedules.

Despite the slow progress of geological repositories in many countries, advances have been made in some parts of the world. In the United States, the Waste Isolation Pilot Plant (WIPP) deep repository for transuranic wastes has been operating successfully for ten years. In Finland, Sweden, and France, deep repository programs are very advanced, proving that sites can be selected with the consent of local populations; that all necessary technologies are mature enough for implementation; and that definitive dates for repository operation can be set. In most other countries of the world, the combined technical and societal approaches employed in Sweden and Finland are looked upon as role models. In 2008, when the U.S. Department of Energy submitted a license application for a geological repository at Yucca Mountain, the U.S. program was also perceived as being one of the most advanced. However, with the mid-2009 declaration by the new administration that Yucca Mountain is "not an option," the timescales to implementation may have been set back by decades.

The various stages in the fuel cycle have often been developed by focusing on how to optimize a specific process and not by taking into account influences on later stages. In the following sections, we present some back-end examples that illustrate this point and that highlight how more holistic thinking might drive future developments.

Storage. There are no major technical issues affecting the safety and security of spent-fuel storage. Both wet and dry storage systems have been proven over decades. However, a specific disadvantage of pool storage is that a large facility must be constructed at the outset to allow for future accumulation of spent fuel. Another disadvantage is that maintenance can become expensive if final disposal lies far into the future. Pool storage has also been criticized as being particularly susceptible to terrorist attacks, although such vulnerability has also been refuted by technical bodies.

The security and terrorist concerns mentioned above have heightened interest in the potential advantages of building storage facilities underground.

This approach has recently been considered in the work of the Committee on Radioactive Waste Management (CoRWM) in the United Kingdom, where such stores are referred to as "hardened" facilities. An alternative would be to have spent-fuel storage facilities at repository depths (hundreds of meters) with the possibility of later converting these stores into final disposal facilities. Others have suggested, however, that this appears more like an effort to place waste in a geological facility without first having to demonstrate the suitability of the site for long-term isolation.

Globally, the spent fuel in storage will continue to grow over the coming decades. Even the first repositories in Sweden, Finland, or France will not begin operation for more than a decade, for technical and engineering reasons. Repositories in other countries will be established much later because of institutional delays, because sufficient inventories must first accumulate, or because funding is not yet available. Revived interest in reprocessing (but not at the present time or with the current technology) will lead some countries to extend surface storage in order to keep the option open. Therefore, global efforts are needed to ensure that safety and security are guaranteed at all storage facilities for spent fuel.

Reprocessing. Reprocessing was first developed on a large scale in military facilities in order to separate fissile materials for nuclear weapons. The environmental impacts, the security aspects, and the treatment of waste residues had lower priorities. The technologies commercially applied today are basically the same as they were when the technology was first developed, although much improvement has been made in reducing emissions and developing conditioning methods for non-high-level waste. Today, there is increased interest in recycling, but based on new developments that provide enhanced security by avoiding separated fissile materials.

The advantage of the current PUREX process is that it has been demonstrated to work in a highly reliable fashion. Key disadvantages are that it produces separated plutonium, which is a security risk, and that the plants required are large and expensive. Alternatives are being worked on. The UREX process, developed in the United States, is modified to separate only the uranium, which can be recycled, leaving the plutonium with the fission products and other actinides in "proliferation resistant" form. The COEX (co-extraction of actinides) process, developed in France, leaves a small amount of recovered uranium with the plutonium so that the plutonium is never separated. Approaches using pyrometallurgical and electrolytic processes to separate the fission products from the actinides have been developed and even operated at the pilot plant stage, but not under the current regulatory regimes, which may present significant challenges to their widespread use.

Geological Disposal. Geological disposal of high-level radioactive wastes and spent fuel is the key part of the nuclear fuel cycle that has not been demonstrated in practice. Technologies have been developed and extensively tested in a number of countries. These technologies are based on different conceptual designs for deep repositories; there are multiple feasible options for the choice of engineered barrier to enclose the used nuclear fuel and also for the geological medium in which the repository will be sited. In all of the programs, the safety of the deep geological system—as assessed by the range of scientific methodologies developed for this purpose—is invariably shown to be high. In the scientific community there is general acceptance of the feasibility of safe disposal, if the site and engineered system are well chosen. Unfortunately, political and societal acceptance remains a challenge in most countries.

The technical concepts developed to date in many countries are, however, generally recognized to be advanced enough for implementation. This does not imply that further technical optimization is unnecessary. In fact, even the most advanced programs are still amending engineering details in order to make the operations in a deep repository safer and more efficient.

The largely technical information about the nuclear fuel cycle discussed so far makes clear that the necessary technologies for open or closed cycles have been developed to a level that allows their industrial application. Furthermore, it is clear that the nuclear fuel cycle is a global enterprise. This is in part because of the widespread and heterogeneous distribution of uranium ore bodies and partly because of the technological development history. The global distribution of fuel-cycle technologies today is determined by various factors, including:

- The military origins and continued attractions of nuclear technology; this led to the present situation of seven countries with fuel-cycle capabilities that include reprocessing;
- The distribution of natural resources; this has led to countries like Australia, with no nuclear power ambitions of its own as of yet, being directly involved in the fuel cycle as a producer of uranium ore;
- The desire for some degree of self-sufficiency in energy supply; this is a key driver in countries like Japan and a claimed driver in others like Brazil and Iran;
- The real or perceived opportunity to provide commercial services to other countries; this is a driver for enrichment and reprocessing facilities in Europe, the United States, and Russia; and
- The recent hunger for clean base-load electrical energy; this is today leading to declarations of interest in expanding or introducing nuclear power in a long list of countries.

This global situation is in a state of flux. The economics and politics of energy supply are changing, and this will have repercussions on many aspects of supply and demand in nuclear fuel-cycle services. More importantly, however, the issues of global safety and security are becoming of increasing concern. Intensive debate on these issues has taken place over the past years. Most emphasis has been placed on restricting the spread of enrichment and reprocessing technologies since these can directly produce weapons-usable materials. A more comprehensive approach, however, seeks to control the distribution of all nuclear materials that can be misused by states or by terrorist groups. In this section, we look at actual or potential geopolitical developments in the global fuel cycle that could lead to increased security risks and at measures that could mitigate these risks.

Nuclear programs expand and seek more independence. The spread of nuclear power reactors alone can obviously increase security risks at the back-end as well as the front-end of the fuel cycle. Since new nuclear programs have insufficient spent-fuel inventories to justify repository projects and since there are currently few fuel providers that accept the return of spent fuel, expansion of reactor operations will also expand storage operations. If the stores are to operate for a very long period, then they will have to be maintained and safeguarded. These tasks become more necessary as the radiation from the spent fuel decays to levels that allow easier handling. Expansion of nuclear power plants thus implies that increased efforts to ensure safe and secure storage of spent fuel are needed. International initiatives have been suggested to meet this need.

Greater security concerns will arise if increased use of nuclear power by some states leads them to conclude that they should implement indigenous facilities for sensitive fuel-cycle activities: reprocessing or enrichment. Both of these activities are economically justified only if a sufficiently large nuclear fleet is operated (or if services are provided to foreign countries). Still, some countries may be tempted to push for national fuel-cycle facilities even if they do not have this level of nuclear power production. Assurance of supply and national independence are obvious drivers. Since mastering either of the two sensitive technologies brings a nation close to the point where nuclear weapons can be produced, there is great international concern about the spread of these technologies.

Uranium producers move into other stages of the fuel cycle. At present, the high-tech stages of the nuclear fuel cycle are carried out by countries with nuclear weapons programs and/or with advanced civilian nuclear power programs. Some of the biggest uranium producers—Australia, Kazakhstan, and Namibia—fall into neither of these categories. It is not unreasonable for such countries to evaluate periodically the potential economic benefits of moving farther up the supply chain rather than simply exporting ores. Enrichment and fuel fabrication are obvious next steps. However, uranium producers could also conceivably offer back-end fuel-cycle services. Reprocessing is unlikely to be introduced where it has not yet been done since very large scale technology is involved, and the economics are not favorable.

An undeniably attractive offer would, however, be a disposal service. In fact, in both Australia and Canada, the two largest uranium producers, the possibility of taking back as spent fuel the uranium that each country has supplied has been debated at different times. It has even been argued that such countries may have a "moral obligation" to accept spent fuel. However, the real driver for a uranium-producing country to accept returned spent fuel for disposal would be economic. Huge benefits could result for the host state, but despite this advantage, the political and public support for such an initiative has nowhere been evident.

Disposal becomes multinational. For some countries, national repositories may be difficult or infeasible because of the lack of favorable geological formations, shortage of technical resources, or prohibitively high costs. Multinational or regional repositories are a potential solution for these countries, and in recent years there has been a rapid increase in interest in this possibility, especially in small countries. The prime drivers were originally the economic and political problems that might be lessened by being shared between countries facing the same challenges. The potential safety and safeguards benefits were also recognized at this early stage. Increasingly—in particular after the terrorist attacks in the United States in 2001 and in connection with nuclear proliferation concerns—attention has focused on the security advantages that could result. The IAEA has been careful to point out that risks must also be minimized at the "back-end of the back-end" of the nuclear fuel cycle—that is, not only in enrichment and reprocessing, but also in storage and disposal (of spent fuel in particular). In its publications in this area, the IAEA has described two potential routes to achieve international disposal: the "add-on approach" and the "partnering scenario."

Both of these potential approaches to multinational disposal have seen significant progress. The add-on option calls for a single country, or a network of countries with appropriate facilities working together, to provide extended fuel-cycle services to countries adhering to the Nuclear Non-Proliferation Treaty (NPT) and wishing to use nuclear power. This option could limit the spread of those sensitive technologies allowed under the Treaty—namely, enrichment, reprocessing, and accumulation of stocks of spent fuel. Crucial prerequisites would be securing supply of services to all cooperating users and close international monitoring by the IAEA.

Within this international fuel cycle scheme, the fuel leasing component is perhaps the most promising. The U.S. government has indicated its support for such a scheme in Russia through the Global Nuclear Power Infrastructure (GNPI) proposal or in the United States through the Global Nuclear Energy Partnership (GNEP) initiative. The proposals are primarily aimed at making the nuclear fuel cycle more secure, but they ultimately require the fuel suppliers to take back the spent fuel or for a third-party, trustworthy country to offer storage and disposal services. Unfortunately, neither initiative appears to be making much progress.

In both Russian and U.S. proposals, the service providers concentrate on offering enrichment, fuel supply, and reprocessing to client countries. Although both proposals mention the take-back of spent fuel, this is a sensitive political issue in both countries. Even if in the future it becomes acceptable to return to U.S. or Russian manufacturers fuel that they had provided to client nations, this take-back will solve only part of the problem. Spent fuel from other suppliers in the market must also be accepted; there are existing inventories of hazardous radioactive wastes that must also go to a deep disposal facility. A more comprehensive offer of disposal services is necessary. In fact, an offer of this type may be the only sufficiently attractive inducement for small countries to accept the restrictions on their nuclear activities that are currently being proposed by the large powers and the IAEA. The emphasis on ensuring security of supply of other services, such as reactor construction, fresh fuel, enrichment, and reprocessing, is misplaced. All of these services are supplied commercially at present, and a customer country currently has a choice of suppliers that may well be wider than would result from implementation of initiatives that create a two-tier system of nuclear supplier and user countries. The key inducement for small countries to give up some of the "inalienable" rights afforded them in Article IV of the NPT may well be the offer of a safe, secure, and affordable route for disposal based on a multinational repository in another country.

The second option for implementing multinational repositories—partnering by smaller countries—has been particularly supported by the European Union through its promotion of the potential benefits of shared facilities in a regional solution. For the partnering scenario, in which a group of smaller countries cooperates in moving toward shared disposal facilities, exploratory studies have been performed most recently by the Arius Association, which also co-managed the European Commission's SAPIERR (Strategic Action Plan for Implementation of European Regional Repositories) project on regional repositories. The project, funded by the European Commission, has carried out a range of studies that lays the groundwork for serious multinational negotiations on the establishment of one or more shared repositories in Europe. The studies have looked at legal and liability issues, organizational forms, economic aspects, safety and security issues, and public involvement challenges. The proposal that resulted from SAPIERR was a staged, adaptive implementation strategy for a European Repository Development Organisation (ERDO).

At the pilot meeting of potential participants in an ERDO working group, thirty-two representatives from fourteen European countries were present, all of whom had been nominated through their national governments, as well as observers from the IAEA, the European Commission, and American foundations. ERDO, if sufficient numbers of partner nations agree to the final proposals, will operate as a sister organization to those waste agencies from European countries such as France, Sweden, Finland, and Germany that have opted for a purely national repository program.

If nuclear power is to expand in a safe, secure, and environmentally friendly manner, improvements in the back-end of the nuclear fuel cycle must occur in the coming years. This section outlines some recommendations, both technical and institutional, for improvement.

Centralized storage—maybe even underground. Concentrating national inventories of spent fuel at a few centralized locations rather than having distributed stores (some at decommissioned reactor sites) can obviously help reduce security risks, from malevolent acts in particular. Some countries already have underground storage facilities and others are considering this option. Given the increasing recognition that spent fuel is a valuable resource—but that reprocessing is currently very expensive—the probability that used fuel will be stored for many decades is rising. If this happens, then the arguments in favor of underground stores with enhanced safety and security will grow stronger.

Research on advanced reprocessing. The recent support for nuclear expansion in some countries has also led to proposals for expansion of reprocessing using the current technological approaches originally developed for extraction of plutonium for weapons. The GNEP initiative proposed implementing reprocessing facilities that were copies of current commercial plants. The scientific community, however, led by the National Academies in the United States, was quick to point out that this is unnecessary and uneconomic at the present time, and that it could lead to increased rather than decreased proliferation risks. Nevertheless, the ultimate need to recycle fissile materials was accepted, and the conclusion was drawn that research into advanced reprocessing technologies is the most appropriate strategy today. Future technologies may improve the economics, environmental impacts, and security aspects.

Optimization of engineering aspects of repositories. A variety of repository designs and operational concepts have been developed over the last thirty years. Most of these, however, have tended to be highly conservative, with the explicit aim of demonstrating that deep geological facilities can provide the necessary isolation of long-lived radioactive wastes over unprecedented timescales up to one million years. Relatively soon, the first facilities will be licensed and constructed, and therefore practical engineering issues will rise in importance. Mining and nuclear working methods must be coordinated in a manner that ensures operational safety and efficient operation. Quality assurance is a key challenge. In addition, the potential for cost savings must be addressed. The work in the advanced Swedish and Finnish spent-fuel disposal programs illustrates this well. In both of these cases, the original massive copper container has been redesigned to use less copper and more steel. Other disposal programs with differing safety concepts will likely face similar challenges.

Technical and financial assistance to new nuclear states. Leading nuclear nations must commit to work closely with young or new nuclear power nations to help them meet their energy needs and aspirations in a manner that preserves and improves security, nonproliferation objectives, transparency, and stability. The leading nuclear nations will have much better chances for success in assuring continued nuclear safety, security, nonproliferation, and environmental preservation if they work proactively with emerging nations to understand and help them improve their nuclear capabilities.

Providing technical and, in some cases, financial assistance to help emerging nations realize a secure and healthy energy future will be an excellent investment if it results in relationships that promote a high-quality nuclear safety and security culture. In the context of this essay, it is important to note that the assistance offered should extend to the back-end of the fuel cycle. An improved approach would be for providers of front-end services and of nuclear power plants to bundle support for repository design and construction activities with back-end services.

Multinational reprocessing facilities. Reprocessing plants that separate uranium, plutonium, and wastes from spent nuclear fuel can divert the plutonium to weapons use as well. As a result, there have been several attempts to pursue multinational solutions, though with little success to date.

With the spread of nuclear power, the advent of new technologies, and a greater focus on assuring decades-long supply of fresh fuel for nuclear plants, more countries may begin to consider the value of developing indigenous reprocessing facilities. It has also been argued that implementing this technology can ease the problems of waste disposal. However, the waste disposal advantages associated with reprocessing are not enough to justify the technology on their own. Thus, there are ample incentives to pursue the creation of multinational enrichment and reprocessing capabilities. Providing a framework that makes emerging nuclear nations meaningful participants in such initiatives holds great promise for better meeting both the energy and security needs of all involved.

Multinational interim storage facilities and repositories. As already emphasized, new nuclear nations will need assistance, particularly at the "back-end of the back-end" of the fuel cycle. Leading nuclear nations have the opportunity to craft "win/win" relationships by recognizing that many small nuclear programs, or countries starting out in nuclear energy, do not have the technical or financial resources to implement a national repository in a timely fashion. They will have to keep their spent fuel in interim storage facilities; this could result in numerous sites worldwide where hazardous materials could be stored for anywhere from decades to hundreds of years. Multinational cooperation in storage and disposal offers a better alternative.

One safer and more secure option would be for nuclear fuel suppliers to take back the spent fuel under fuel "leasing" arrangements, as described earlier. However, although there is fierce competition among nuclear suppliers to provide reactors, fuels, and reprocessing services, as yet few are willing to pursue this leasing approach. Moreover, some would-be supplier nations, such as France, even have national laws prohibiting spent fuel take-back unless the high-level wastes are returned to the user after reprocessing. The user country would therefore still require a geological disposal facility for these wastes. Cost savings, if any, in implementing a high-level waste repository rather than a spent-fuel repository would be far outweighed by the prices charged for the reprocessing service.

The most promising option that remains open for small and new nuclear power programs is to collaborate with similarly positioned countries in efforts to implement shared, multinational repositories. The possibility that some country may decide to offer international repository services on a commercial basis cannot be excluded and could be a game-changer.

The big challenge, of course, is achieving public and political acceptance in the repository host countries. Is it conceivable that a country and a local community within that country would willingly accept being a host for imported wastes? Recent national siting experience gives hope. Siting initiatives in several countries for either high- or low-level wastes have shown that success can be achieved through a modern strategy based on open communication, transparent documentation of potential benefits to host communities, steady accumulation of trust by the organization developing the repository, and recognition of the necessity of local acceptance. In a few countries (for example, Finland, Sweden, and South Korea), this has even led to competition between communities wishing to host a repository. At the multinational level, it is possible that the same strategy may also succeed, but as in the successful national programs, this may take several years.

The ERDO initiative mentioned above could act as a role model for regional groupings elsewhere. A number of Arab states have recently made clear that they intend to introduce nuclear power, and have expressed a willingness to do so collaboratively. For example, in the Gulf Region, the United Arab Emirates is developing a complete roadmap, planning all of the activities involved in introducing nuclear power. Close linkages being formed today between nuclear programs in Brazil and Argentina might usefully expand into a Central and South American grouping. In Asia, countries like Taiwan and South Korea have already experienced problems trying to implement disposal programs, and various other Asian states, such as Malaysia, Indonesia, and Vietnam, have nuclear ambitions. An African regional grouping could also emerge, as various nations there have expressed interest in nuclear energy.

Joining forces in developing regional repositories could still have substantial advantages for small nuclear countries, even if the major nuclear powers at some stage reverse their policies and, for strategic or commercial reasons, finally do offer to accept foreign spent fuel or radioactive wastes. With a united front, and with the open alternative of a multinational regional repository, the partner countries would be much better placed in negotiations with potential large service providers over the economic and other conditions attached to any offer to take their spent fuel.

If the spread of nuclear energy production is to occur without increasing global risks of terrorism and nuclear proliferation, there must be close international scrutiny of all nuclear activities. This oversight will be easier if sensitive materials in the nuclear fuel cycle are handled, stored, and disposed of at fewer locations. Shared disposal facilities for the spent fuel and highly radioactive wastes at the back-end of the fuel cycle should be one key component in a secure global system. It would benefit all nuclear programs if initiatives for regional cooperation were started in relevant parts of the world by small or new nuclear countries, and if these initiatives received technical and moral support from the advanced national disposal programs.

Today, developed and emerging countries are striving to maintain or improve their standards of living by assuring a sufficient supply of energy; at the same time, they are striving to deal responsibly with global warming. Accordingly, prospects for a substantial growth and spread of nuclear power and associated facilities are increasing. For this growth to be successful, however, there are a number of concerns that need to be addressed, some technical and some economic. The potential for a systems approach to technical and economic optimization should certainly be examined, explicitly taking into consideration the holistic nature of the fuel cycle. The technical and economic challenges associated with expansion of nuclear power are, however, outweighed by the institutional concerns that need to be addressed.

Because the nuclear fuel cycle is global and because the consequences of misuse of nuclear materials are also global, all nations can be affected by the expansion of nuclear power. Multinational cooperation is essential for ensuring safety, security, and protection of the environment during this expansion. This cooperation must extend to the back-end of the nuclear fuel cycle.

Recent policy initiatives have focused on incentives to nations in the form of fresh fuel assurances in return for promises by recipient nations not to pursue indigenous enrichment or reprocessing. These offers have met with less than popular acceptance. To many in the emerging nuclear world, fresh fuel assurances by the developed nuclear nations look like the start of a nuclear fuel cartel. The assurances appear to perpetuate a division between nuclear haves and have-nots, and ask emerging nuclear states to put themselves in a political situation that they believe might threaten their access to fuel in coming decades. Many would prefer a continuation of what they feel they already have: access to a healthy nuclear fuel marketplace.

Nonetheless, revisiting the nuclear bargain established by the NPT and related agreements is being pushed—for different reasons—by both the nuclear-weapons states and the emerging nuclear nations. These efforts present both a concern to many that the NPT may be fraying at the edges, but also a possible opportunity to build a new set of understandings and behavior that will better meet the energy, proliferation, and environmental needs of all concerned.

We should start with a set of clear goals. These goals must be responsive to the needs of the entire international community, not just those of the advanced nuclear provider states. The goals must also include measures at the back-end. The complete list of goals could include:

- Providing access to nuclear power at market prices for any country that desires it;
- Assuring nuclear fuel supplies through a fuel bank and healthy marketplace;

- Eliminating the rationale for enrichment and reprocessing for all but a select few, and ensuring that when these activities do take place they are under international control/oversight;
- Securing all excess weapons-usable material by putting it in unattractive form or burning it where sensible, and bringing it under international control in appropriate countries; the ultimate goal is to draw down separated weapons-usable materials to as close to zero in as few places as practical;
- Disposing of spent nuclear fuel domestically or shipping it to appropriate countries for management and disposal under international oversight;
- Recognizing countries that agree to host multinational disposal facilities as providers of a necessary nuclear fuel-cycle service;
- Entitling all countries that provide fuel-cycle services at the front-end or back-end to reasonable commercial profits;
- Entitling countries that use foreign fuel-cycle services at the front-end or back-end to security of supply; the unique nature and particular risks associated with nuclear power technologies imply that the above two points must be internationally guaranteed if the free market system fails to work effectively; and
- Ensuring that any move toward weapons development or weapons-usable material acquisition is surely, quickly, and clearly apparent.

Effectively integrating a successful approach to spent fuel and high-level radioactive waste management is a crucial component of pursuing such an agenda. The lack of a credible, sustained program to provide an ultimate solution to the disposal of these materials is a serious hindrance to a healthy nuclear power program. The growth and spread of nuclear power may well lead to more countries accumulating spent fuel. The subsequent buildup of this material in an increasing number of nations will provide a reservoir of plutonium that could later be accessed through reasonably quick and simple, and possibly covert, reprocessing techniques. Along with the spread of expertise and necessary technical knowledge, this buildup can bring countries closer to weapons creation and potentially set off regional instabilities as neighbors begin to hedge their nuclear bets as well.

Creating an international initiative to explore the prospects for multinational spent-fuel storage, with eventual multinational disposal of spent fuel or the high-level waste resulting from reprocessing, can begin a win/win process for solving the waste issue in a manner that addresses proliferation, energy, and waste management issues simultaneously. Companion efforts could pursue multinational enrichment facilities and, as needed, reprocessing facilities with opportunities for financial participation by emerging nuclear nations.

Established nuclear nations, particularly the nuclear-weapons states, should lead by example. As leaders, they can transform waste management and disposal from issues of "nuclear garbage" to integral elements of an internationally accepted system. This system not only would provide for the resurgence of nuclear power, but in doing so would simultaneously reduce proliferation, regional instability, and waste management concerns.

CHAPTER 2

Possible International Fuel-Cycle Arrangements Attractive to States during the Nuclear Power Renaissance

Noramly Bin Muslim

The nuclear fuel cycle consists of a series of steps that both produces fuel for nuclear power reactors, which in turn generate electricity, and handles the spent fuel afterward. The steps involved in preparing uranium, including enrichment, for use in power reactors make up the front-end of the fuel cycle. After its use in power reactors, the spent fuel, which contains plutonium and high radioactive waste as by-products, is removed from the reactor, cooled, stored, and possibly reprocessed to separate the fuel (for recycling) from the waste. During reprocessing, plutonium is separated from the uranium. The extracted plutonium can be reused as reactor MOX fuel for further generating of electricity, or it can be used as fissile material for nuclear weapons. This series of processes represents the back-end of the fuel cycle.

The production of nuclear fuel can serve both peaceful and military purposes. Therefore, the nature of the fuel-cycle activities allows for the creation of civilian nuclear power for electricity generation, as well as the production of weapons-grade fissile material. This dual use of uranium fuel gives rise to two major problems: one related to the risks of nuclear proliferation and the other related to the management of generated radioactive wastes and spent fuel. The increase in the global demand for energy will lead to expansion in the use of nuclear energy. Experts project that global nuclear power capacity will double by 2030. Lately, more than sixty emerging and developing countries have notified the International Atomic Energy Agency (IAEA) of their interest in the option of utilizing nuclear power plants to generate electricity and the power needed in desalination plants. Most of these countries currently do not have established nuclear power industries, the trained personnel, or the necessary legal framework and institutions to support a nuclear power program.

As of today, some 440 power reactors operate in 31 countries. Very few of these countries possess uranium and plutonium reprocessing technologies. Although the majority of them do not pose a proliferation concern, they do possess the technical capabilities, experience, and know-how to divert fissile material for military purposes.

Access to sufficient energy supplies will continue to be the dominant factor in a state's pursuit of prosperity. This "nuclear renaissance" scenario should lead to an increase in demand for fuel-cycle services. It could also lead to an increase in the proliferation risks created by the spread of sensitive nuclear technology, such as that used in uranium enrichment and spent-fuel reprocessing. Wide dissemination of these technologies could be the Achilles' heel of the nuclear nonproliferation ideal. The convergence of these trends points to the need for the development of a new multilateral framework for the fuel cycle. Such a framework could best be achieved through establishing mechanisms to ensure the supply of fuel for nuclear power plants and perhaps over time of converting national enrichment and reprocessing facilities to multilateral operations. This could lead to a situation where future enrichment and reprocessing would be limited to multilateral operations. The director general of the IAEA has called for the creation of this multilateral mechanism to ensure supplies of nuclear fuel and services to countries that need them (assurance of supply and services), as well as for strengthening nonproliferation through better controls over sensitive parts of the nuclear fuel cycle (enrichment and plutonium separation) by way of multinational approaches to the front-end and the back-end of the nuclear fuel cycle (assurance of nonproliferation).

MULTILATERAL PROPOSALS

A number of proposals have been put forward by IAEA member states, groups of states, the nuclear industry, and international institutions aimed at preventing the spread of uranium enrichment and nuclear fuel reprocessing technologies. These international efforts are focused on establishing a system of guarantees and assurances to customer countries that they will have reliable nuclear fuel supply after meeting their nonproliferation criteria. Yuri Yudin, of the United Nations Institute for Disarmament Research, cites the following twelve proposals:

1. U.S. Proposal on a Reserve of Nuclear Fuel (United States, September 2005)
2. Russian Global Nuclear Power Infrastructure, or GNPI (Russian Federation, January 2006)
3. U.S. Global Nuclear Energy Partnership, or GNEP (United States, February 2006)
4. World Nuclear Association Proposal (World Nuclear Association, May 2006)

5. Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel (France, Germany, The Netherlands, Russian Federation, United Kingdom, and United States, June 2006)
6. IAEA Standby Arrangements System (Japan, September 2006)
7. IAEA Fuel Bank (Nuclear Threat Initiative, September 2006)
8. Enrichment Bonds Proposal (United Kingdom, September 2006)
9. International Uranium Enrichment Center (Russian Federation, January and May 2007)
10. Multilateral Enrichment Sanctuary Project (Germany, May 2007)
11. Multilateralization of the Nuclear Fuel Cycle (Austria, May 2007)
12. Nuclear Fuel Cycle Non-Paper (European Union paper, June 2007).

The proposals that are being put forward on multilateral approaches to the nuclear fuel cycle vary considerably in their objectives, vision, scope, targets, and time frame required for their implementation. Many are limited in their goals, and some deal only with the front-end of the fuel cycle—relating to the supply of nuclear fuel and enrichment services. The Russian GNPI and the U.S. GNEP proposals have far-reaching visions for global supply, but they are still vague and need to be further refined. The Austrian proposal's vision of placing all sensitive technologies and activities under multilateral control is rather bold. Some of the other proposals focus on the short term and are more specific; others are concerned with the medium or long term. None of the proposals listed above clearly addresses issues related to the removal of spent nuclear fuel, the supply of spent-fuel storage, or other back-end services.

It is noteworthy that none of the above approaches was proposed by a developing country or by a group of developing countries, which, in principle, would be the most interested parties and would benefit most from these arrangements. All of the proposals came from traditional "nuclear supplier" countries as their own initiatives or came through international organizations. Developing countries, therefore, are studying these proposals to ensure they reflect their interests and limitations.

SPENT-FUEL DISPOSAL AND STORAGE FACILITIES

Little serious discussion is taking place on proliferation related to "the back-end of the back-end" of the nuclear fuel cycle, namely spent-fuel disposal and spent-fuel storage. Currently the responsibility lies solely with the nation concerned, and there is no international facility providing spent-fuel disposal services or spent-fuel storage. The final disposal of spent fuel is a potential candidate for multilateral approaches, which may appeal to states with smaller civil nuclear programs.

Storage facilities for spent fuel are in operation and are being built in many countries. However, there are no international services offered in this area, except for those of the Russian Federation, which is ready to accept spent Russian-supplied fuel from client countries. This operation is a good candidate for multilateral approaches primarily at the regional level. Storage of such nuclear materials in safe, secure facilities would enhance safeguards and physical protection. It would minimize the costs of maintaining such facilities in countries with small nuclear power programs. Perhaps it is an opportune moment for the IAEA to encourage the development of such facilities and services under multilateral control in emerging countries.

FUEL LEASING AND TAKE-BACK MODEL

The combined option of fuel leasing/fuel take-back, whereby the leasing state provides the needed fuel through an arrangement with its nuclear-fuel vendor, has advantages. The leasing state issues an export license to its fuel vendor to send fresh fuel to a client reactor. The spent leased fuel, once removed from the reactor and cooled down, can then be returned to its country of origin or sent through the IAEA to a third party or to a regional or multinational center elsewhere, for storage and, ultimately, disposal. The inherent problems related to the international transport of highly radioactive materials are being considered in this option.

Spent-fuel disposal, spent-fuel storage, and the fuel-leasing/fuel take-back combined option have their own problems related to the willingness to accept these "wastes," as it is politically difficult and sensitive for states to accept spent fuel that is not produced in their own reactors. States with suitable disposal sites that are concerned about proliferation ought to seriously consider the fuel-leasing/take-back proposal as it may also offer a considerable commercial opportunity.

MULTILATERAL APPROACHES

As commonly indicated, multilateral approaches to the nuclear fuel cycle by no means constitute a "magic bullet" that can solve the world's nonproliferation problems. They cannot eliminate proliferators, but at the very least they can ensure that emerging states enjoy the benefits of nuclear energy while strengthening the nuclear nonproliferation regime, ensuring safe and secure management of the nuclear fuel cycle, and reducing national incentives for newcomers to build their own nuclear fuel-cycle facilities, thus avoiding the high cost and related technical problems.

New multilateral nuclear fuel-cycle policies should not deprive customer states of any of their rights as stipulated under the Nuclear Non-Proliferation Treaty (NPT) regime. The use of nuclear energy for peaceful purposes should continue to be strongly supported as one of the three fundamental pillars of the NPT, along with disarmament and nonproliferation. Increased resources should be provided, including those offered through the IAEA's Technical Assistance Program, to assist emerging and developing countries in taking full advantage of the potential of peaceful nuclear energy to aid human development and improve quality of life. Greater multilateralization of the nuclear fuel cycle and government cooperation on proliferation-resistant technologies are other measures designed to reduce risks associated with the expansion of civil nuclear energy.

NUCLEAR RENAISSANCE

The days of discriminatory technology denial are over in a fast-developing world. States should move toward technology governance. Long-term success will require new initiatives whereby the developing countries gain access to critical technologies while being fully committed to nonproliferation. Keeping them engaged and involved in all discussions and in the formulation of proposals will lessen their concern of being deprived of their "inalienable right" to the peaceful uses of nuclear energy provided for under Article IV of the NPT. Offers of political and economic incentives as well as assistance to achieve a certain level of governance for sustainable implementation of measures designed to prevent proliferation could dissuade developing countries from pursuing sensitive fuel-cycle technologies. Promotion of international cooperation on nuclear energy infrastructure designed to raise awareness worldwide of the importance of the three S's—Safeguard, Security, and Safety—should be encouraged. The IAEA and its member states should make more of an effort to focus on how to reconcile the anticipated expansion of nuclear power with the anger associated with proliferation. At the same time, the nuclear-weapons states should take steps toward meeting their disarmament obligations as stipulated under the NPT.

Nuclear power is now widely accepted as an important alternative source of energy for socio-economic development, with advantages over other energy sources, including reliability, security, zero-carbon emissions, and being global in character. States seeking to benefit from nuclear energy need a substantial legal and technical infrastructure to build and operate nuclear power plants safely and securely. They also need to ensure that the operation of these plants conforms to international nonproliferation commitments and norms. Building capability and acquiring the technological know-how are lengthy and demanding processes. Information exchange on needs and trends, concerns about civilian nuclear power and its nuclear fuel cycle, human resource development, and international cooperation are essential to assisting interested countries toward realizing the benefits of nuclear power.

Newcomers planning for nuclear power programs should study and compare the twelve multilateral proposals listed above. They should consider their goals, targets, methods, and eligibility, as well as the roles of the industry and any potential concerns. No single proposal will suit all countries.

Two major problems for developing nations include how to benefit from the back-end of the fuel cycle and how to avoid burdensome costs and delays in their nuclear programs. Based on the available information, the best solutions proposed to date appear to be the Russian GNPI and the U.S. GNEP proposals. These proposals offer the most far-reaching visions for global supply mechanisms, addressing services ranging from enrichment and fuel supply to spent-fuel take-back and reprocessing. The success of these proposals will depend on the long-term development of new technologies to establish the necessary infrastructure and overcome political, technical, and legal obstacles and challenges.

The Austrian proposal offers a bold conceptual vision of eventually placing all sensitive nuclear technologies and activities, including current civilian enrichment and reprocessing facilities and fuel supply, under multilateral control. Although the proposal is still vague, this concept has potential and merits further consideration. More refinement, further discussions, and greater scrutiny are needed to overcome the political reluctance that such a proposal might generate.

THE WAY FORWARD

Although the nuclear programs of many emerging countries may not materialize even after the usual lead-time of ten years or more, preparations and discussions on meeting various milestones and other international and multilateral obligations must begin now. States have to be involved in all discussions and issues pertaining to the safe implementation of their civil nuclear programs.

In the past, nuclear cooperation took place under bilateral intergovernmental arrangements. Indeed, the nuclear renaissance is taking place in an increasing atmosphere of bilateral interaction, bundled with extensive technical support provided by vendors.

However, when it comes to the steps within the nuclear fuel cycle concerning enrichment and reprocessing, multilateral arrangements are needed. It is in the interest of developed nations and nuclear vendors to promote such multilateral solutions for pressing issues related to the fuel cycle and nuclear proliferation.

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CHAPTER 3

New Approaches to the Nuclear Fuel Cycle

Tariq Rauf[1]

For the past five decades, the role of nuclear power has been shaped by many factors, such as growing energy needs, economic performance, the availability of other energy sources, the quest for energy independence, environmental factors, nuclear safety and proliferation concerns, and advances in nuclear technology. For a variety of reasons, including climate change, enhanced safety, and improved technology, a revival of nuclear energy as a clean fuel seems in the offing—and a nuclear renaissance is widely expected with the attendant issues of security of the supply of technology and fuel, as well as verification of the peaceful use of nuclear energy.

The long-term prospects for nuclear power, however, will depend on the industry's success in addressing concerns associated with spent-fuel management, including waste disposal, proliferation, safety, and security, while improving economic competitiveness of future reactors. Interest in starting new nuclear power programs remains high, with more than sixty member states of the International Atomic Energy Agency (IAEA) having expressed such interest. Nearly twenty IAEA member states are currently involved in projects to develop reactor and fuel-cycle designs that would address some of the concerns noted above.

In recent years, front-end issues have been driven by considerations of increased demand for nuclear fuel, as existing users of nuclear energy build new facilities and new countries develop nuclear power programs. It has also been driven, concomitantly, by fears of other countries of the spread of uranium enrichment and the rise of clandestine nuclear supply networks. With regard to increased reliance on nuclear power, the question is: From where would the new fuel supply come? Would it remain in the hands of the existing suppliers, who would then perhaps expand the capacity?[2] Would new countries develop

1. The views expressed in this essay are the author's alone.

2. Currently there are thirteen enrichment facilities in nine countries. IAEA-TECDOC-1613 (Nuclear Fuel Cycle Information System, A Directory of Nuclear Fuel Cycle Facilities, 2009 Edition), Table 14, p. 55; Tables 17–22, pp. 55–56); http://www-pub.iaea.org/MTCD/publications/PDF/te_1613_web.pdf.

their own national indigenous enrichment capabilities beyond market requirements, or would international nuclear fuel-cycle facilities emerge to meet the demand for nuclear fuel services?

Back-end concerns (disposal of spent or irradiated nuclear fuel) remain essentially the same as those that prevailed in the past (that is, the management of spent nuclear fuel and the disposal of radioactive waste). More than fifty countries currently have spent fuel from power or research reactors stored in temporary locations awaiting reprocessing or disposal. Not all countries have the appropriate geological conditions or geographical location for such disposal—and, for many countries with small nuclear programs for electricity generation, the financial and human resource investments required for the construction and operation of a geological disposal facility remain daunting.

The current spectrum of policy and technology issues underlies the current impetus for greater innovation in the search for possible solutions that could lead to new international or multinational approaches (MNAs) to the nuclear fuel cycle for both the front-end and the back-end.

Attempts in the 1970s and 1980s to set up multinational approaches to the nuclear fuel cycle did not yield tangible results for a variety of political, technical, and economic reasons, but principally because countries could not agree on the conditions and nonproliferation commitments for participation in the multilateral activities. National sovereignty considerations also played a role, alongside expectations about the technological and economic spin-offs to be derived from nuclear fuel-cycle activities. Thirty years later, the same concerns still prevail as new approaches are suggested.

So far, efforts have not been successful to promote a new binding international norm stipulating that sensitive fuel-cycle activities are to be conducted exclusively in the context of MNAs and no longer as a national undertaking, because this is regarded as changing the scope of Article IV of the Nuclear Non-Proliferation Treaty (NPT). Discussions both with supplier states but, more important, with consumer states have shown that different states would choose different policies and solutions for their nuclear energy policy options. This in turn would depend on their historic situation, as well as on their geographical location, technical abilities, resources, and individual choices. Thus, in this context, it is of the utmost importance that flexibility is exercised and that there are no attempts to suggest solutions that are perceived to be imposed, particularly on the consumer states. Establishing MNAs with voluntary participation is the way to proceed.

In the current discussions on MNAs, IAEA member states have been interested in promoting front-end initiatives, specifically the assurance of supply of low-enriched uranium (LEU) and the possibility of setting up international uranium enrichment centers. Back-end issues have not featured in such MNA discussions.

FRONT-END: ASSURANCE OF SUPPLY

Recent proposals for assuring supplies of LEU for power reactor fuel, in the author's view, could be seen as one stage in a broader longer-term development of a multilateral framework for nuclear energy. Such a framework could encompass assurance-of-supply mechanisms for both natural and low-enriched uranium, as well as for nuclear fuel. Once a multilateral framework for the front-end is established, it could be possible to establish a similar framework for spent-fuel management at the back-end of the nuclear fuel cycle. This separation of effort is driven by the technical complexity of the nuclear fuel cycle and the political sensitivity of its numerous aspects. In this context, establishing a fully developed multilateral framework that is equitable and accessible to all users of nuclear energy is a key element for IAEA member states and NPT states.

An assurance-of-supply mechanism for the front-end of the nuclear fuel cycle could potentially address two challenges. The first is to deal with the possible consequences of interruptions in the supply of nuclear fuel resulting from political considerations that are unrelated to nonproliferation or commercial, technical, or other aspects in terms of fulfillment of contractual obligations. Such interruptions might dissuade countries from initiating or expanding nuclear power programs. The second challenge is to reduce simultaneously the vulnerabilities that might create incentives for countries to build new national enrichment and reprocessing capabilities beyond market-driven requirements.

Hence, an assurance-of-supply mechanism would be envisaged solely as a backup mechanism to the operation of the current normally functioning market in nuclear materials, fuels, technologies, and so on. This would not be a substitute for the existing market, and it would not deal with disruption of supply stemming from commercial, technical, or other failures.

A summary of existing proposals is available on the IAEA's website (http://www.iaea.org). Presently, there are twelve mutually complementary proposals. These proposals range from providing backup assurance of the supply by governments, to establishing an IAEA-controlled LEU reserve, to setting up international uranium enrichment centers where the IAEA would have some role in the decision-making. All of these proposals are currently under consideration among the IAEA member states.

By June 2009, three front-runner concepts had emerged on assurances of supply: the establishment of an IAEA LEU bank, the Russian Federation initiative to establish a reserve of LEU for supply to the IAEA for its member states, and the German Multilateral Enrichment Sanctuary Project. In addition, the United Kingdom is developing its nuclear fuel assurances. These proposals aim to add to states' nuclear fuel options by backing up the commercial market with an assurance-of-supply scheme for eligible states, which would increase confidence in continuing reliance on nuclear power.

The first two front-runner concepts noted above call for the establishment of LEU reserves under IAEA auspices. An IAEA LEU bank is envisaged to hold 60 tonnes of LEU that would be sufficient to meet the electricity needs of two million average Austrian households for three years. In addition, in November 2009, the IAEA Board of Governors decided by a vote to accept the Russian Federation proposal to set up a reserve with 120 tonnes of LEU, for use by IAEA member states; the legal instruments to put this into effect are expected to be signed soon.

BACK-END INITIATIVES

Once nuclear fuel has been used in a nuclear power plant to produce electricity, the fuel has been "spent" and it awaits further treatment in a reprocessing facility to recover the uranium and plutonium contained in the waste, or in an intermediate storage facility, or in a "final repository" as a terminal solution.

Among the more visible efforts to promote MNAs for the back-end were the IAEA study on Regional Nuclear Fuel Cycle Centers (1975–1977), the International Nuclear Fuel Cycle Evaluation program (1977–1980), the Expert Group on International Plutonium Storage (1978–1982), the IAEA Committee on Assurances of Supply (1980–1987), and the Conference for the Promotion of International Cooperation on the Peaceful Uses of Nuclear Energy. In a general sense, these efforts concluded that most of the proposed arrangements were technically feasible and that, based on the projections of energy demand, economies of scale rendered them economically attractive. Nonetheless, all of these initiatives failed for a variety of political, technical, and economic reasons, as noted above.

In general, thus far, MNAs may have been more successful in uranium enrichment[3] (front-end) than in the field of spent-fuel reprocessing. In part, in the author's view, this may be because for now reprocessing technology requires greater financial investment and involves more technical complexity.

Growth in reprocessing capacity has been somewhat limited and currently is about 5,000 tHM (tonnes of heavy metal) per year. All reprocessing facilities are owned directly by governments or by companies controlled by governments.

The total amount of spent fuel that has been discharged globally from nuclear reactors is about 320,000 tHM. About one-third of the spent fuel that has been discharged from power reactors has been reprocessed. The rest is in interim storage. A significant fraction of the separated plutonium is used for MOX fuel for light-water power reactors. The rest is in interim storage. By the end of 2009, about 95,000 tonnes of spent fuel had been reprocessed, and

3. The two uranium enrichment consortia, Urenco and EURODIF, are institutional expressions of the movement toward a European indigenous enrichment capability. In spite of initial difficulties, they came to represent two different economic and industrial models of multinational ownership and operation, neither of which was established for explicitly nonproliferation purposes, but both of which contributed to that end.

about 225,000 tHM are stored in spent-fuel storage pools at reactors or at other storage facilities.

World capacity to reprocess light-water reactor fuel is expected to exceed demand until plutonium recycling becomes more economical with the introduction of fast reactors or with a substantially increased uranium price. In the meantime, with the availability of several capable suppliers, the market stands ready to provide adequate assurance of reprocessing services. A state that agrees to rely on international (rather than domestic) reprocessing facilities to have its spent fuel reprocessed, and to use the separated plutonium and/or uranium in MOX fuel, would want some assurance that the reprocessing services would be available as needed. Otherwise, the state would want an assurance that a package of reprocessing and MOX fabrication would be available as necessary. There are also other options, such as fuel leasing and take-back, which would become more feasible when supplier states have in place a closed fuel cycle and reprocess spent nuclear fuel from thermal reactors, both domestic and foreign, to fabricate fuel for fast reactors.

With regard to interim and final storage and disposal, the fact is that most of the spent fuel around the world is now kept at the nuclear plants themselves, where it has been used. Depending on the option selected, a final repository may receive unprocessed fuel assemblies (spent or irradiated fuel), or plain wastes, or both. Whether such special facilities would be candidates for multilateral approaches is an open question. Besides the expected economic benefits of multinational repositories, there may be a reason to view them in terms of nonproliferation in the case of spent fuel, because of the potential risk associated with the contained plutonium, whose accessibility increases with time given the radiological decay of the associated fission products.

No shared multinational repository exists currently, and at present, there would be strong public opposition to such repositories. It is difficult enough to have a national repository. This situation may change, however, when several national repositories have been built and put into operation.

At the national level, Sweden has selected Östhammar as the site for a final spent-fuel geological repository, following a nearly twenty-year process, with operation targeted for 2023. Site investigations for repositories at Olkiluoto in Finland and in the Bure region in France have continued on schedule, with operation targeted for 2020 and 2025, respectively.

In the United States, the government decided to terminate its development of a permanent repository for high-level waste at Yucca Mountain, and has signaled that it intends to withdraw the license application that was submitted to the NRC in 2008. In the meantime, the NRC has been asked to put the application on hold and DOE has not requested any funding for FY 2011. A Blue Ribbon Committee has been established to study alternative routes for spent-fuel management and to report within twenty-four months. In the United Kingdom, a voluntary siting process has been initiated.

Multinational repositories, in the author's view, could offer numerous economic benefits for both the host and partner countries with small nuclear programs. Sharing a facility with a few partners could significantly reduce a host country's expenditures. Because the host country would bear the burden of permanently housing the repository (and because some partners may be saving the costs of establishing their own centralized facilities), the host country likely would negotiate an equitable contribution from its partners toward the total development costs of the project. Partner countries could agree to pay the host country some of the costs of development, but also a fee on the operation of the site. Therefore, a multinational agreement would spread the full burden of development costs among several partners, thereby significantly reducing these costs for individual members. In most countries, a fee is levied on each nuclear kilowatt-hour (kWh) produced, prior to construction of disposal facilities.

The final disposal of spent fuel also could be a candidate for multilateral approaches, because this could offer major economic benefits and substantial nonproliferation benefits. There would be legal, political, and public acceptance challenges in many countries, however.

To be successful, the final disposal of spent fuel (and radioactive waste) in shared repositories could be considered as one element of a broader strategy of parallel options. National solutions will remain a first priority in many countries. This is the only approach for states with major nuclear programs in operation or in past operation. For others with smaller nuclear programs, a dual-track approach could be considered in which both national and international solutions may be pursued.

FUEL-CYCLE CENTERS

The concept of "fuel-cycle centers" also deserves consideration. Such centers would combine, in one location, several segments of the fuel cycle (for example, uranium processing and enrichment, fuel fabrication [including MOX], spent-fuel storage and reprocessing). Regional fuel-cycle centers could offer most of the benefits of other MNAs, in particular, material security and transportation. A further step—the additional co-location of nuclear power plants—would create a genuine "nuclear power park," an interesting, more long-term concept that deserves further study. For new models of cooperation, there could be options for companies serving different parts of the fuel cycle to cooperate in a way that could supply customer states with various (or all) required services for using nuclear energy.

CONCLUSION

In the present context of Atoms for Peace, over the medium to long term, new frameworks could be considered for the use of nuclear energy to achieve the following objectives:

- Robust technological development and innovation in nuclear power and nuclear applications; and
- New multilateral approaches for the nuclear fuel cycle, for both the front-end and the back-end, to assure supply and build confidence in continuing reliance on nuclear energy while strengthening the nuclear nonproliferation regime.

CHAPTER 4

Not Second but First Place for the United States

Atsuyuki Suzuki

Concerns associated with the management of spent nuclear fuel are widespread and are compounded by the lack of transparency in North Korea's spent fuel program. One way to minimize these concerns is to establish an international spent-fuel facility with high standards and rigorous requirements that can be achieved with maximum transparency.

The question, then, is how do we pursue a multilateral effort to select a site on which to build and operate an international spent-fuel facility for either interim storage or final repository? There are two perspectives that need to be considered. The first belongs to countries that might be willing to host such a facility, the second to client countries seeking to place their spent fuel at the facility. Given the highly controversial nature of this issue, both perspectives deserve serious consideration, and key to such a strategy will be to create economic, political, and social incentives that are acceptable to all parties involved.

For a potential host country, the benefits of receiving other countries' spent nuclear fuel must far outweigh the costs associated with constructing and operating the facility. In addition, the host country would need assurances that the facility did not pose significant risks to public health or to the environment. In most cases, host countries would have to change their current laws before a facility could be built, and no such action would occur without first establishing these assurances. Countries willing to take these steps would, in effect, demonstrate their long-term commitment to hosting a facility on their soil.

Moreover, both the host country and the global public must share the belief that all states have a right to the use of nuclear energy for peaceful purposes. A state hosting an internationally managed facility should therefore have to commit to accepting spent fuel produced not only as a result of civilian activities but also as a result of nuclear disarmament, thus enhancing overall transparency, because a facility with this guarantee would be more likely to attract global public support and dilute deep-seated mistrust from a legacy of past defense programs. Weapons-states must signal to the global public that they are taking concrete steps toward dismantlement and that they are decommissioning their nuclear plants according to internationally recognized transparency standards.

Client countries, of course, would also want certain economic benefits. The direct costs for domestic interim storage are relatively small, and international storage may not produce any savings. Taking into account the indirect costs associated with long-term storage, however, and all of the obligatory security and nonproliferation measures this entails, international storage might begin to appear more economically appealing.

The question, then, is to what extent are such indirect costs incurred internationally? Naturally, small states would prefer to minimize these costs, which is one reason for their hesitancy in engaging in long-term, domestic, interim storage of spent fuel. To stimulate participation in an international venture, it may be necessary to provide these states with budgetary assistance. This would also help to ensure their safe and secure use of nuclear energy.

Another overriding issue involves nonproliferation. Given the sensitivities of states over the nature of spent nuclear fuel, they must possess a high level of confidence in the political and institutional stability of a potential host country. Otherwise, discussion of establishing a spent-nuclear-fuel facility should not move forward. Overall, the nonproliferation views of the host country, clients, and original suppliers of the nuclear fuel, which, in some cases, may have prior consent rights over the nuclear materials involved, should be compatible. For example, in the event the material in question is of U.S. origin, a decision to transfer it to a storage or disposal facility in another country would be subject to the prior approval of the United States. No such approval should be forthcoming unless the United States is fully satisfied with the nonproliferation policies of the host country, as well as with the safeguards and physical arrangements associated with any nuclear waste transfer.

President Barack Obama has clearly signaled to the global community his desire to take a leadership role in nuclear disarmament. In his 2010 State of the Union Address, President Obama declared that he would not accept second place for the United States, while emphasizing that the country's greatest source of strength has always been its ideals. To demonstrate international leadership and his commitment to those ideals of safety, security, and nonproliferation, President Obama should propose that the United States host a spent-nuclear-fuel facility on its soil.

The Obama administration has already decided that Yucca Mountain is no longer an option as a disposal site for defense- and civilian-related spent nuclear fuel. The United States, however, has another facility—the Waste Isolation Pilot Plant (WIPP)—that currently disposes of long-lived (as opposed to high-level) radioactive waste produced in the making of nuclear weapons. Given that the geological environment at the WIPP site appears scientifically suitable for highly radioactive waste as well, it would make sense to look into the possibility of using the WIPP facility for the disposal of waste produced from both civilian and defense programs. The United States would thus signal to the world community that high-level radioactive waste can be disposed of safely.

One conceivable approach would involve the United States establishing an international interim storage facility to receive spent nuclear fuel from other countries, using the WIPP as a pilot repository. Countries participating in this endeavor could receive subsidies through an international funding mechanism, to encourage participation and mitigate security and nonproliferation concerns.

U.S. willingness to host an international spent-nuclear-fuel facility would have several positive effects. First, it would send a message to people around the world that a future in which nuclear energy plays a significant role can be achieved. Second, it would lend tremendous encouragement to the development of similar projects. For example, given prior U.S. consent, Japan, Korea, and Taiwan might explore the possibility of a joint endeavor to share their fuel-cycle activities at the regional level. Third, once the U.S. initiative proves successful, increasing numbers of countries would seek to participate, eventually reducing the overall number of countries maintaining their own domestic spent-fuel management programs. Finally, the increased transparency produced by this initiative would help greatly to reduce security and nonproliferation concerns worldwide.

CHAPTER 5

Spent-Fuel Management: The Cases of Japan, South Korea, and Russia

Frank von Hippel

In their article on "The Key Role of the Back-End in the Nuclear Fuel Cycle," Charles McCombie and Thomas Isaacs are correct in asserting that the non-proliferation regime would be strengthened and nuclear energy costs could be reduced if a few multinational spent-fuel repositories could be built instead of every nation having to build its own. The concern is that, if spent fuel is left in national control indefinitely, some nations might mine it for plutonium to make weapons.

Below, I discuss the cases of Japan and South Korea, whose nuclear utilities have been unable to site even interim storage facilities. They are therefore, respectively, reprocessing and considering reprocessing. Then I discuss the case of Russia, which, in the early 2000s, was seen as the country most likely to be willing to dispose of other countries' spent fuel. I end with a short note on the politics of siting geological radioactive waste repositories.

JAPAN

Japan, the only non-weapons state that reprocesses its spent fuel, provides a perfect example of how a country, not being able to solve its spent-fuel storage problem, might turn to spent-fuel reprocessing as a way to buy time—even though reprocessing is enormously expensive, complicates ultimate radioactive waste disposal, and creates security concerns.[1]

1. The discussion in this section is based in large part on Tadahiro Katsuta and Tatsujiro Suzuki, *Japan's Spent Fuel and Plutonium Management Challenges* (Princeton: International Panel on Fissile Materials, 2006), and Masafumi Takubo, "Wake Up, Stop Dreaming: Reassessing Japan's Reprocessing Program," *Nonproliferation Review* (March 2008): 71.

Japan's nuclear utilities have not been able to persuade the prefectures (Japan's equivalent of states) that host their nuclear power plants to allow them to do what almost all U.S. nuclear utilities have done when their spent-fuel pools are dense-racked and almost full: build on-site dry-cask storage for spent fuel that has cooled down for twenty years or so. Japan's nuclear utilities have therefore been forced to ship their spent fuel off-site. Here, again, they encountered a problem: no prefecture wanted to host a central interim spent-fuel storage site for fear that it would become permanent. In any case, Japan's nuclear establishment initially favored reprocessing because it expected to move relatively quickly to plutonium-breeder reactors that would require a large amount of separated plutonium for start-up cores. In the late 1970s, therefore, Japan's nuclear utilities entered into reprocessing contracts with France and the United Kingdom and, in the 1980s, began to ship spent fuel to those two countries for reprocessing.

This solution provided only temporary relief, however, because the contracts with France and the United Kingdom required Japan to take back the high-level radioactive waste (HLW) produced by the reprocessing. After a decade or so, Japan was faced with having to find a national interim storage site for HLW coming back from Europe. This proved to be no easier than finding a central interim storage site for spent fuel.

This time, Japan's utilities solved their problem by building a domestic reprocessing plant, including a storage facility for the HLW coming back from Europe. In 2003, the Federation of Electric Power Companies of Japan estimated that building, operating, and decommissioning the plant, fabricating the plutonium into MOX fuel, and disposing of the associated transuranic waste would cost about ¥13 trillion (about $130 billion at an exchange rate of ¥100 per dollar).[2] In addition, they committed another ¥1 trillion to the host prefecture to be paid over the forty-year lifetime of the reprocessing plant. These are huge costs—more than $3 billion per GWe (gigawatt-electric) for the approximately 40 GWe of nuclear capacity that the reprocessing plant will service if it operates at full capacity.[3] The utilities argue, however, that the alternative of shutting down all of their nuclear power plants would be even more costly.[4]

2. This estimate by the Federation of Electric Power Companies of Japan of the total cost of reprocessing at Rokkasho is reported in *Nuke Info Tokyo* (98) (November 2003–February 2004), http://cnic.jp/english/newsletter/nit98/nit98articles/nit98rokleaks.html.

3. In August 2009, the start-up of full operations of Japan's new Rokkasho Reprocessing Plant, originally scheduled for 2002, was postponed for the seventeenth time by technical problems, until at least the end of 2010; "Reprocessing plant startup delayed," *Asahi Shimbun*, August 31, 2009.

4. Japan Atomic Energy Commission, New Nuclear Policy-Planning Council, *Interim Report Concerning Nuclear Fuel Cycle Policy*, November 12, 2004. English translations of the key conclusions can be found on the Citizens' Nuclear Information Center, http://cnic.jp/english/topics/policy/chokei/longterminterim.html. The utilities calculated that the extra cost of reprocessing plutonium relative to spent-fuel interim storage would be ¥0.6/kWh (kilowatt hour). For 40 GWe of nuclear capacity operating for forty years, this would cumulate to ¥7.5 trillion.

SOUTH KOREA

South Korea, whose nuclear program is about twenty-five years behind that of Japan and is encountering similar opposition to expanded on-site storage from the local governments hosting its nuclear power plants, is also proposing to reprocess.[5] Some South Koreans also advocate reprocessing because they believe that it would be useful to have the nuclear-weapons option that reprocessing would provide. Indeed, the calls for "nuclear sovereignty"—that is, obtaining U.S. consent to South Korean reprocessing—reached a crescendo after North Korea's May 2009 nuclear test.[6]

RUSSIA

The George W. Bush administration must have been thinking of Russia when it proposed a "Global Nuclear Energy Partnership," in which a few "fuel-cycle" countries that were already reprocessing spent fuel on a large scale would dispose of the spent fuel of "reactor" states, such as South Korea. The fuel-cycle states would reprocess the reactor-state spent fuel, recycle the recovered transuranic elements in fast-neutron reactors until they were fissioned (except for process losses), and dispose of the foreign reprocessing waste along with their own waste. Indeed, the Soviet Union had provided spent-fuel take-back services for the Eastern European countries to which it had exported reactors and had reprocessed some of the repatriated spent fuel. Furthermore, in 2001, the year that the Bush administration took office, Russia's Ministry of Atomic Energy (MinAtom) succeeded in getting a law through the Duma that would allow it to import spent fuel into Russia "for temporary technological storage and (or) reprocessing." The law is ambiguous on what is to happen to the reprocessed waste, however, because it requires that MinAtom reserve the "right to return radioactive wastes resulting from reprocessing to the country of origin of the spent fuel."[7]

South Korea and Taiwan were the potential customers mentioned most frequently by MinAtom. The United States, however, has "consent rights" on transfer of most South Korean and all Taiwanese spent fuel to any third country, and it requires assurance that the spent fuel will not be reprocessed with-

5. Frank von Hippel, "South Korean Reprocessing: An Unnecessary Threat to the Nonproliferation Regime," *Arms Control Today*, March 2010, 22–29.

6. Lee Jong-Heon, "South Koreans call for nuclear sovereignty," UPI, June 15, 2009; and Jungmin Kang, "The North Korean nuclear test: Seoul goes on the defensive," *Bulletin of the Atomic Scientists*, June 12, 2009.

7. This section is largely based on "Russia's Nuclear-Energy Complex and its Roles as an International Fuel-Cycle-Services Provider," *Global Fissile Materials Report 2007* (Princeton: International Panel on Fissile Materials, 2007), chap. 8.

out its permission. The United States might eventually give its consent to the reprocessing of South Korean and Taiwanese spent fuel in Russia if Russia promised that it would not return the separated plutonium to Taiwan and South Korea. These negotiations, however, could take years.

In the meantime, Rosatom, MinAtom's successor agency, is less desperate for money than MinAtom was in the 1990s. The idea of importing foreign spent fuel excited opposition from a large spectrum of Russia's social and local constituencies. MinAtom was able to persuade the Russian government to override this opposition, but Rosatom's current management is more reluctant to initiate nuclear projects against public opinion. On July 11, 2006, Rosatom's head, Sergei Kirienko, announced: "Russia has not imported foreign spent fuel, is not importing and will not import it in the future."[8] With little political resistance, Rosatom is building a huge, interim spent-fuel storage facility at an uncompleted reprocessing facility near Krasnoyarsk. It plans eventually to reprocess much of this spent fuel for start-up cores for plutonium breeder reactors and may return to the idea of reprocessing other countries' spent fuel as well.

RISK PERCEPTIONS ABOUT GEOLOGICAL RADIOACTIVE WASTE REPOSITORIES

Objectively, the politics of radioactive waste repositories are perplexing. Intuitively, it seems obvious that relatively cool spent fuel buried 500 meters underground should represent a much smaller risk than the hot spent fuel in power reactor cores or recently discharged spent fuel in dense-packed spent-fuel pools.

Perhaps this comparative perspective is the reason why communities in Finland and Sweden that already host nuclear power plants have volunteered to host underground repositories.

The United States, which currently operates more than a quarter of the world's nuclear generating capacity, should be willing to take the spent fuel of other countries with smaller programs as a way to strengthen the nonproliferation regime. Increasing by 10 to 50 percent the amount of spent fuel to be disposed of would not qualitatively change the U.S. spent-fuel disposal challenge. To show leadership in advancing multinational spent-fuel management arrangements, however, the United States would need to put its own spent-fuel politics in order. Unfortunately, by proposing to cancel the Yucca Mountain repository and making no attempt to establish a fairer site selection process for a future repository, Barack Obama's administration has set the United States up for a renewed debate over the reprocessing of its own spent fuel.

8. Ibid.

CHAPTER 6

Addressing the Nuclear Fuel Cycle: Internationalizing Enrichment Services and Solving the Problem of Spent-Fuel Storage

Ellen Tauscher

President Barack Obama's administration is working on many fronts to solve some of our toughest problems, including health care, the economy, climate change, and terrorism.[1] As you know, the demand for clean energy is growing. This means that nuclear power is likely to be an important part of our low-carbon energy future, at least until my former constituents at Lawrence Livermore National Laboratory finally deliver on the promise of fusion.

We must address two challenges as nuclear energy expands worldwide:

- First, we must ensure that the expansion of nuclear energy does not lead to the spread of enrichment and reprocessing technologies that can be used to make nuclear materials for nuclear weapons.
- Second, we must develop a practical plan for the management of spent fuel.

These two goals are interrelated in various ways. The connection I want to emphasize is that cooperation on spent-fuel management can reduce global demand for indigenous enrichment and reprocessing.

President Obama addressed precisely these issues last spring in Prague when he set forth the ambitious goal of building "a new framework for civil nuclear cooperation . . . so that countries can access peaceful power without increasing the risks of proliferation."

As we at the State Department work to ensure that civil enrichment and reprocessing technologies do not contribute to weapons proliferation, the most direct approach, as is often the case in life, is not the most productive.

1. This essay is based on remarks given on January 19, 2010, at the Hoover Institution at Stanford University.

The previous administration proposed to ban these technologies for states that do not already possess them. The problem was that all other countries opposed this approach because they viewed it as an infringement on their sovereignty and on their Nuclear Non-Proliferation Treaty (NPT) rights to peaceful nuclear technology. Moreover, the very insistence that others not obtain such capabilities increased demand for them by creating the impression that we are seeking to establish a suppliers' cartel. Instead of reassurance, this had the opposite effect.

As President Obama said in Prague, "No approach will succeed if it's based on the denial of rights to nations that play by the rules." So the administration is focusing on creating incentives for states considering nuclear energy to choose not to pursue sensitive fuel-cycle technologies.

The primary incentive not to pursue an indigenous enrichment capability is the existence of a strong, competitive commercial market. Any state or reactor operator in good standing with its nonproliferation obligations seeking uranium-enrichment services may receive four bids—from URENCO, USEC, AREVA, and TENEX. Many contract with all four to diversify their supply. The enrichment industry is investing heavily to upgrade technology and expand to meet projected demand. In addition, a fifth potential competitor is developing innovative laser technology. These suppliers, which are international in character, with production facilities in six countries, have a proven track record for producing enriched uranium reliably and economically.

This international enrichment enterprise is fully integrated into a global fuel supply chain, including international providers of uranium, conversion services, and fuel fabrication, with a track record of reliable performance on long-term contracts. This competitive commercial market is the bedrock incentive to forgo costly and complex indigenous enrichment programs.

For those who seek additional confidence beyond what the market provides, however, the United States is leading the international community to develop assurances of reliable fuel supply, beginning with fuel banks. As you have noticed, after forty years of discussion, the International Atomic Energy Agency (IAEA) Board of Governors approved in November 2009 the first enriched uranium reserve, at Angarsk, in large measure due to a cooperative diplomatic effort of the United States and Russia.

If a country in good standing with its nonproliferation obligations encounters a supply problem and is unable to find a commercial solution, it could turn to the IAEA, which in turn could request enriched uranium from the Angarsk reserve. In a manner consistent with its national laws, Russia could transfer the material to the IAEA, which would arrange for fabrication into fuel and delivery to the country in question.

This all sounds straightforward, but there are underlying challenges that need to be reconciled, including:

- The IAEA's perceived need to determine eligibility only on the basis of the record of compliance with safeguards;

- The laws of supplier countries placing much more stringent conditions on transfers of enriched uranium, including the Nuclear Suppliers Group (NSG) guidelines; and
- A feeling on the part of many developing countries that fuel assurances are intended ultimately to preserve a choke hold over nuclear fuel supplies and to deny them their NPT rights to nuclear technology.

The Obama administration worked with Russia and the IAEA to reconcile these divergent considerations in a manner that won the approval of a large majority of the IAEA Board.

We are now using the precedents established by Angarsk to shape the international nuclear fuel bank put forward by the Nuclear Threat Initiative, with the objective of bringing this second and complementary fuel-bank proposal to the IAEA Board in Spring 2010.

In addition, the United States is creating a national enriched-uranium reserve to support fuel-supply assurances by downblending highly enriched uranium no longer needed for national security purposes.

As fuel banks have made the transition from discussion to reality, we are exploring other concepts to assure a reliable fuel supply, in particular, backup arrangements between suppliers and consumers such as the "enrichment bond." Under a concept put forward by our British friends, supplier governments would commit, under certain conditions, not to prevent their companies from supplying enriched uranium.

These various forms of assurance of a reliable supply of nuclear fuel are designed to serve as safety nets, to enhance confidence for countries that rely on the commercial market for nuclear fuel and to reduce pressure to pursue indigenous sensitive fuel-cycle facilities. The Obama administration strongly supports the creation of these safety nets.

Looking to the future, a more ambitious and controversial approach would be to create internationally controlled enrichment centers. Proponents envision international control as a way to provide reliable fuel-supply services without putting sensitive enrichment technology in the hands of more countries.

This idea, however, has its own set of problems, including questions concerning how an international organization would manage safety regulation, make export control decisions, raise the immense funding required, gain access to competitive technology, and maintain security of enrichment technology. The disastrous loss of URENCO centrifuge technology, and proliferation of that know-how, illustrates the potential problem of maintaining technology security in multinational organizations.

There are also questions of how to integrate international enrichment centers with the existing commercial market. New international suppliers could add diversity, but we do not want to disrupt the commercial market, which is working well today and provides a strong incentive not to pursue indigenous enrichment.

The interrelationship between commercial enrichment enterprises and international centers could become complex if, as seems likely, commercial enterprises provide the technology and operating facilities for international centers on a black-box basis. Whether internationally controlled enrichment centers represent a creative idea somewhat ahead of its time remains to be seen.

In parallel with these multilateral efforts, the United States is using bilateral nuclear cooperation to build mutual confidence and to welcome decisions to abstain from indigenous enrichment and reprocessing.

We have signed bilateral memoranda of understanding with Jordan, the United Arab Emirates, Saudi Arabia, and Bahrain that express their intention to rely on international markets rather than enrichment and reprocessing on their territories.

As a matter of policy, we will continue to encourage states to take advantage of the international fuel market and to welcome decisions to refrain from enrichment and reprocessing by states that do not have these capabilities.

We believe there is great value in having the U.S. government and U.S. industry deeply involved in the nuclear programs of developing countries, to help create high standards for safety and security and nonproliferation. For exports of U.S. nuclear technology, this requires conclusion of Agreements for Nuclear Cooperation (so-called 123 agreements).

As an example of the importance we attach to these issues, I recently traveled to Amman to work with the government of Jordan to develop a path forward on a 123 agreement.

By law, 123 agreements are sent to Congress for review. It is therefore a joint responsibility of the administration and the Congress to take account of the particular situation of each country and region in developing agreements that enable the deep involvement of U.S. industry and not leave the field entirely to others who may not share our nonproliferation standards.

Let me now turn to the disposition of spent reactor fuel. In contrast to the front-end of the nuclear fuel cycle, where there is a strong, competitive commercial market, disposition of spent fuel is an unresolved problem for nearly all countries. This is a challenge and a potential opportunity for us to advance our nonproliferation goals.

No nation, with the possible exception of Sweden and Finland, has satisfactorily resolved the question of the disposition of spent fuel once it is discharged from a power reactor. The United States is putting its best and brightest to work on this problem.

Today's technology provides two unattractive choices:

- One is isolation in a geological repository for tens of thousands of years. This is politically and technically difficult, and throws away the majority of the potential energy value, which might be needed in the future, depending on the scale of expansion of nuclear energy, the availability of uranium resources, and the availability of improved technologies to extract additional energy without increasing proliferation risks, none of which are known today.

- The other is reprocessing to recover uranium and plutonium, followed by the use of the plutonium to produce MOX fuel for light-water reactors. Reprocessing with current technology is uneconomical, as MOX fuel is more expensive than LEU. Reprocessing does not significantly reduce the waste burden, but passes it on in the spent MOX. And reprocessing has resulted in large stocks of separated plutonium—about 250 tons, and growing about 10 tons per year. The growing worldwide stockpiles of separated plutonium as a by-product of reprocessing spent civil reactor fuel represent one of our greatest nonproliferation problems.

So the Obama administration is focusing on research to create better options:

- If fast neutron reactors could produce electricity as reliably and economically as today's thermal reactors, they would open the way to a new fuel cycle without separation of plutonium. Much of today's stockpile of separated plutonium was created in anticipation of the advent of fast reactors. Unfortunately, the sixty years of experience with fast reactors have been problematic, and commercial deployment for economical production of electricity is not in sight.
- High-temperature reactors have potential for high burn-up of uranium and plutonium, and a proliferation-friendly, once-through fuel cycle.

These and other concepts are being actively pursued with our international partners in the Generation IV International Forum, for potential deployment in future decades.

This leads to the question of what we can do today to help countries considering nuclear energy in dealing with the back-end of the fuel cycle. If we could offer a way to help relieve nuclear newcomers of the burden of disposition of spent fuel, that would be attractive and could provide an advantage as we seek to achieve our goal of strengthening nonproliferation as nuclear energy expands. A key part of the answer is interim storage.

Nuclear power is the only industry I know where the short term is fifty years. So what we are looking for is placement of spent fuel in a storage facility for fifty to a hundred years with the ability to retrieve it at any time. From a technical point of view, dry cask technology is proven and licensed and available for this purpose.

We will not know for decades the full extent of the demand for nuclear fuel due to the expansion of nuclear energy. Nor will we know the availability of the uranium resource that can be recovered at reasonable cost. Nor will we know which technologies will become available to overcome the economic and proliferation drawbacks of reprocessing as practiced today.

Retrievable interim storage would preserve options for future decisions when we have the information necessary to make informed choices on what to do with spent fuel.

The question becomes where to store spent fuel. Part of the answer is in the same country—usually at the same site—where the fuel was irradiated. The United States and others can assist a country seeking nuclear energy in implementing a safe, secure, and economical system for interim storage on the reactor site or elsewhere in that country.

The answer could also include international storage. Today, Russia is the only country taking back spent fuel, and only from Russian-supplied reactors. There is potential for the development of a broader application of interim storage in Russia of fuel irradiated in other countries. But Russia has no interest in being the only destination for spent fuel, and the corresponding leverage Russia would gain in the sale of fresh fuel would surely distort the market.

One can argue that it would be in the interest of the United States and other suppliers of reactor technology and fuel to take back spent fuel for storage. At present, bringing to the United States spent fuel irradiated in nuclear power plants abroad requires notification of Congress, which would almost certainly lead to congressional opposition to such imports. While the odds are against us, we could work with Congress to seek an ability to offer interim storage of spent fuel from abroad, for countries that do not have sensitive fuel-cycle facilities.

Establishment of regional or international interim storage facilities could make an important contribution to an attractive offer for countries considering nuclear energy. Spent fuel could be stored at the reactor site for a period of time, followed by storage at an international facility, followed by a decision on ultimate disposition.

Finding suitable locations that would welcome such a facility would not be easy. Resolving questions of cost, responsibility, and liability are serious challenges. The potential benefits would be substantial and would justify a major effort. Our goal is to cooperate with other governments to open the way for the international nuclear industry to offer the same reliable and economical services at the back-end of the fuel cycle that they now provide at the front-end.

Indeed, comprehensive fuel services, including fuel leasing and take-back options—"cradle to grave," in the words of my friend and colleague Deputy Secretary of Energy Dan Poneman—would be attractive to governments and operators as an alternative to the costs, complexities, and burdens of sensitive fuel-cycle facilities.

Through international cooperation, we can achieve the goals President Obama set forth in Prague. Together with our international partners, we can discourage the spread of sensitive technologies, while we support expansion of peaceful nuclear energy, without calling into question the rights of countries that abide by their nonproliferation obligations.

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The Global Nuclear Future Initiative of the American Academy

There is growing interest worldwide in civilian nuclear power based on the recognition of its potential for meeting increased energy demands. But the spread of nuclear technology, in the absence of rigorous safety regimes, presents unique security risks, including the potential proliferation of weapons capabilities to new states, sub-national, and terrorist groups.

The Academy's Global Nuclear Future Initiative is working to prevent this dangerous outcome by bringing together constituencies that historically have not communicated effectively—from government policy-makers to heads of nongovernmental organizations, from nuclear engineers to industry leaders, from social scientists to nonproliferation experts—to establish an interdisciplinary and international network of experts working together to devise and implement nuclear policy for the twenty-first century. Our overriding goal is to identify and promote measures that will limit the security and proliferation risks raised by the apparent growing global appetite for nuclear energy.

To help reduce the risks that could result from the global expansion of nuclear energy, the Initiative addresses a number of key policy areas, including the international dimension of the nonproliferation regime, the entirety of the fuel cycle, the physical protection of nuclear facilities and materials, and the interaction of the nuclear industry with the nonproliferation community. Each of these areas has specific challenges and opportunities, but informed and thoughtful policies for all of them are required for a comprehensive solution. We also recognize that "game changers," developments that could have a tremendous impact but cannot be extrapolated from current trends, could influence the course of events and should be identified and included in our deliberations.

American Academy of Arts & Sciences

The Academy was founded during the American Revolution by John Adams, James Bowdoin, John Hancock, and other leaders who contributed prominently to the establishment of the new nation, its government, and its Constitution. Its purpose was to provide a forum for a select group of scholars, members of the learned professions, and government and business leaders to work together on behalf of the democratic interests of the republic. In the words of the Academy's Charter, enacted in 1780, the "end and design of the institution is . . . to cultivate every art and science which may tend to advance the interest, honour, dignity, and happiness of a free, independent, and virtuous people." Today the Academy is both an honorary learned society and an independent policy research center that conducts multidisciplinary studies of complex and emerging problems. Current Academy research focuses on science and global security; social policy; the humanities and culture; and education. The Academy supports early-career scholars through its Visiting Scholars Program and Hellman Fellowships in Science and Technology Policy, providing year-long residencies at its Cambridge, Massachusetts, headquarters. The Academy's work is advanced by its 4,600 elected members, who are leaders in the academic disciplines, the arts, business, and public affairs from around the world.

The Nuclear fuel cycle is the series of industrial processes that describe uranium throughout its life cycle; from mining to processing to generating electricity and finally to its reprocessing and waste.[1] Essentially all activities involved with nuclear power from its beginning to end are considered to be part of the nuclear fuel cycle. The cycle is split into two parts; the front end and the back end. Front end includes mining, milling, processing, enrichment, and nuclear fuel fabrication. The back end includes the primary goal of the fuel cycle, the generation of electricity, along with t The nuclear fuel cycle, also called nuclear fuel cha in, is the progression of nuclear fuel through a series of differing stages. It consists of steps in the front end, which are the preparation of the fuel, steps in the service period in which the fuel is used during reactor operation, and steps in the back end, which are necessary to safely manage, contain, and either reprocess or dispose of spent nuclear fuel.