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A New Energy Paradigm

Ensuring Nuclear Fuel Supply and Nonproliferation through International Collaboration with Insurance and Financial Markets

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As large-scale risks reshape the future of an increasingly interdependent world, Dr. Michel-Kerjan has worked over the past ten years helping corporations and governments address this new landscape, develop appropriate solutions and create market opportunities. His current work focuses on terrorism risk insurance, climate change, mitigation of natural disasters and the financing of relief efforts, energy interdependence and nonproliferation, the impact of information sharing on optimal risk sharing, and projects on national security and critical infrastructure protection in collaboration with Lockheed Martin and several federal agencies.

He has authored or coauthored over forty publications and two books focusing on the intersection of financial management and global risks/opportunities, including *Seeds of Disaster, Roots of Response: How Private Action Can Reduce Public Vulnerability* (with P. Auerswald, L. Branscomb, and T. LaPorte, Cambridge University Press, 2006), which is the first attempt to analyze the private efficiency/public vulnerability trade-off in the context of national and international security. (See www.seedsofdisaster.com.)

From 2003 to 2005, he served on the OECD Terrorism Insurance Task Force, and in 2005, he co-led, with Howard Kunreuther, the Wharton initiative on the future of terrorism risk financing in the United States (TRIA and Beyond). He has studied and collaborated with several research institutions in North America (including McGill, Columbia, and Harvard) and is also Faculty Research Associate at the Ecole Polytechnique in Paris, where he completed his doctoral studies in mathematics and economics before joining Wharton in 2002.

In 2007, Dr. Michel-Kerjan was named a Young Global Leader by the World Economic Forum, an honor bestowed to recognize and acknowledge the most extraordinary leaders of the world under the age of 40.

A New Energy Paradigm

Ensuring Nuclear Fuel Supply and Nonproliferation through International Collaboration with Insurance and Financial Markets*

Debra K. Decker[1] and Erwann O. Michel-Kerjan[2]

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Abstract

Increases in world population and per capita energy demand in the next few decades are expected to cause a substantial rise in world energy use. In addition, growing concern over carbon-based energy's effect on global warming has revived interest in non-carbon-based energy sources such as nuclear power. Seeking ways to dissuade more states from contemplating launching their own uranium enrichment programs (which could produce not only material for nuclear fuel but also for nuclear weapons), the International Atomic Energy Agency (IAEA) is considering different mechanisms to assure these states that they can obtain fuel supplies from the market without political interference.

Nuclear fuel users, however, care about all aspects of managing the risk of their fuel supplies, not just the politics of obtaining enriched uranium. Moreover, some of these states might be afraid that any solution exclusively supported by the IAEA would still be susceptible to political pressures from certain producer members.

Building on the experience of the nuclear safety/security and catastrophic risk financing fields, we discuss ways the international community could facilitate the development of an insurance market to provide added security. Specifically, we recommend the financial indemnification for economic losses suffered by nuclear utilities (public and private) due to a disruption of supply over the full fuel cycle (enrichment, fabrication, and transportation). One way to achieve that is to establish an international insurance mechanism (e.g., a mutual company) that would both limit the fuel risk of the nuclear facilities and benefit from coverage from a consortium of private insurers and reinsurers. The mechanism could benefit from an additional layer of protection by being backstopped by IAEA member countries.

The eligibility for such insurance coverage and the terms and condition of the indemnification would be analyzed and prespecified. Because this approach would rely on international insurance markets, it could be seen not only as complementary to other proposed solutions but also more neutral.

The mutual company could also use supply options to facilitate fuel deliveries in the event of market interruptions. Support for the commoditization of the uranium market should also be considered.

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"Regarding an assurance of supply mechanism, I should point out two aspects. The first is that it acts like an insurance policy to make sure that all countries that fulfill their non-proliferation obligations are able to get the fuel and the technology they need, without being subject to extraneous political considerations. Such considerations have been applied in the past.

The second aspect—and perhaps the most important to emphasize—is that this is not an attempt to divide the nuclear community into suppliers and recipients. Rather, the aim of the assurance of supply concept is to establish a mutually supportive international project…"

—Mohamed ElBaradei, IAEA Director General, 2005 Nobel Peace Prize Laureate
Vienna, Austria, September 19, 2006

1. Introduction and Background

The need to address nuclear fuel cycle dangers is urgent. Increases in world population and per capita energy demand in the next few decades are expected to cause a substantial rise in world energy use. The International Energy Agency in 2006 predicted global primary energy demand increasing by over 50 percent by 2030.[3] In addition, growing concern over carbon-based energy's effect on global warming has revived interest in non-carbon-based energy sources such as nuclear power. Currently 435 nuclear power plants operate in 30 countries, but an additional 28 plants are under construction, another 64 are planned, and 158 are proposed.[4] Most nuclear reactors use low-enriched uranium as fuel. This fuel is made by mining, converting and enriching uranium ore then fabricating it into fuel rods (see Table 1 below). The problem is that the same process used to enrich uranium for fuel can be used to further enrich uranium to produce weapons-usable material. Thus the international community is thinking hard how to manage the nuclear fuel market.

Debate on the internationalization of the dangerous aspects of the nuclear fuel cycle predates the inception in the 1950s of the International Atomic Energy Agency (IAEA). The issue, never fully resolved,[5] has become even more vexing with the world's changes since the 1950s. The terrorist attacks on September 11, 2001, as well as other attacks before and after, clearly demonstrate that we have entered a new era of large-scale threats. These threats (including nuclear ones) are characterized by their interdependence, which is largely due to the globalization of worldwide social and economic activities. As a result, catastrophic risks are also becoming more global. In other words, any individual, country, or even organization is finding it more difficult to manage these risks alone. Nuclear threats posed by unwatched proliferation possess similar attributes.[6]

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3. International Energy Agency, *World Energy Outlook 2006—Summary and Conclusions*, p. 1, http://www.worldenergyoutlook.org/summaries2006/English.pdf.
4. See appendix I, which provides information for each country.
5. Study and discussions predate even President Dwight D. Eisenhower's 1953 proposal for an international fuel bank.
6. Debra Decker and Erwann Michel-Kerjan, "Ensuring Global Nuclear Fuel Supplies," *International Herald Tribune*, December 22, 2006.

Recently, IAEA Director General Mohamed ElBaradei challenged the world to tackle again the question of ways in which internationalization of the nuclear fuel supply could reduce nuclear fuel cycle dangers and increase assurance of fuel supplies. He commissioned an expert panel to define the best options. The IAEA panel, known as the Expert Group, issued a report in 2005, "Multilateral Approaches to the Nuclear Fuel Cycle," with a good enunciation of various options.[7] The importance of providing some degree of fuel assurance to dissuade states from enriching uranium has also been noted by the United Nations High-level Panel on Threats, Challenges, and Change; the WMD Commission; and the Carnegie Endowment for International Peace.[8]

Countries and other groups have put forward additional proposals that focus on the assurance of physical delivery of enriched fuel to countries that need it and that meet specific predefined criteria (see appendix II). These proposals were explained and discussed at the IAEA Special Event on assurances of supply and nonproliferation in September 2006.[9] This event focused on the front end of the fuel cycle—uranium enrichment.

It is often not in a country's economic interest to begin enriching its own uranium to make fuel for its nuclear reactors. Given industry returns to scale and to significant technological investments, buying enriched uranium from established producers in other countries is currently cheaper, especially for smaller quantities of enriched uranium. Nevertheless, some countries might decide not to buy but to develop their own uranium enrichment capacity on their soil for at least three reasons:

- A full fuel cycle ability provides more commercial and political stability to the nuclear reactors' fuel supply, which in turn lowers the expected discounted cost of the total electric power per kilowatt-hour delivered.

- While providing an assured source of supply, an enrichment facility can also cover part of its cost by providing enrichment services to other countries and other reactors (including research reactors).

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7. International Atomic Energy Agency, "Multilateral Approaches to the Nuclear Fuel Cycle," Expert Group report submitted to the Director General of the International Atomic Energy Agency, INFCIRC/640 (Vienna, Austria: IAEA, February 22, 2005), http://www.iaea.org/Publications/Documents/Infcircs/2005/infcirc640.pdf.

8. Among the most recent ones, see: United Nations, *A More Secure World: Our Shared Responsibility*, Report of the Secretary-General's High-level Panel on Threats, Challenges and Change (New York: United Nations, 2004) http://www.un.org/secureworld/report2.pdf; Weapons of Mass Destruction Commission (Hans Blix, Chairman), *Weapons of Terror: Freeing the World of Nuclear, Biological and Chemical Arms* (Stockholm: Weapons of Mass Destruction Commission, 2006), http://www.wmdcommission.org/files/Weapons_of_Terror.pdf; George Perkovich, Jessica T. Mathews, Joseph Cirincone, Rose Gottemoeller, and Jon B. Wolfsthal, *Universal Compliance: A Strategy for Nuclear Security* (Washington, D.C.: Carnegie Endowment for International Peace, March 2005), http://www.carnegieendowment.org/files/UC2.FINAL3.pdf; and Alexei Arbatov and Vladimir Dvorkin, eds., *Nuclear Deterrence and Non-Proliferation* (Moscow: Carnegie Moscow Center, 2006), http://www.carnegie.ru/en/pubs/books/9735arbatov_eng_blok.pdf.

9. 50th IAEA General Conference, Special Event, *New Framework for the Utilization of Nuclear Energy in the 21st Century: Assurances of Supply and Nonproliferation*, Vienna, Austria, September 19–21, 2006.

- The enrichment capability is often viewed as providing increased prestige and power, and allows for the option of a possible "breakout" to nuclear weapon capabilities.

The goal of fuel assurances, and of the concept of fuel *insurance* introduced in this paper, is to reduce just the first incentive for countries to enrich uranium. And it is clear that should a country focus on the third (desire to develop nuclear weapon power), our proposal would be of limited effect (except that such a country would have even more trouble using the "risk of disruption in fuel supply" card to justify its actions).

No country has yet run into major supply problems due specifically to commercial disruptions. Rising fuel demand and lagging supply availability, however, are expected to keep uranium prices high and markets tight, thereby adding to the interest in supply assurances. Moreover, past political constraints on supply may have partly motivated countries such as Iran to seek enrichment capability. It is unclear thus far what other countries might be on the full-fuel-cycle fence and could be swayed not to enrich by an effective assurance mechanism that addresses simply political risk. It is important that IAEA identify these countries and what assurances they would need so that the best supply assurance mechanism can be crafted.

The methods for providing fuel assurances discussed with the most salience thus far include the provision of IAEA and other joint guarantees on enrichment, the establishment of regional fuel centers, and, most prominently, the development of an IAEA fuel bank stocking low-enriched uranium that could be fabricated to meet the supply needs of a country facing supply chain disruption for political reasons not related to proliferation concerns, as determined by IAEA under prearranged guidelines. At the Special Event in Vienna, the Nuclear Threat Initiative (NTI)—backed by investor/philanthropist Warren Buffet—made a generous pledge of $50 million to IAEA to help create such a low-enriched uranium stockpile.[10] The pledge required IAEA to obtain match-funding of $100 million. The resulting $150 million in enriched uranium would be enough to fuel a typical power reactor.

But this would represent less than 1 percent of that used globally each year,[11] raising the question: what would happen if there were a major disruption that prevented fuel supply for more than 1 percent of what is needed globally (e.g., a major natural disaster that devastates an entire region combined with some political risks associated with international relations between the major producers and other countries in demand)?

One possibility that, to our knowledge, has not been discussed so far would be to provide assurances by making use of the financial capacity of private sector partners who

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10. The funds are conditioned on IAEA approving establishment of the stockpile and raising an additional $100 million in funds or the equivalent value in low-enriched uranium (200 percent matching) in the next two years. Whether the stockpile is real or virtual, how it is controlled, and the requirements for its use are all left up to the IAEA and its members.

11. This was deemed a sufficient amount for last resort assurances, according to former Senator Sam Nunn, cofounder of NTI, as quoted in Michael Adler, "UN Nuclear Watchdog to Discuss Fuel Supply Scheme," Agence France Press, September 19, 2006.

could provide the financial basis as well as expertise in the field of managing large-scale risks. The insurance and reinsurance industry seems to be a very natural candidate for this task. First, this sector has become the largest industry in the world—with $3.4 trillion in yearly premium revenue, plus another trillion dollars in investment income.[12] Second, insurers' and reinsurers' core business is, precisely, dealing with risk management and risk financing optimization. Third, and importantly here, insurers might be perceived as a neutral third party on the international fuel demand/supply scene.

We suggest that IAEA, nuclear utilities and interested countries give additional attention to the possibility of private insurance/mutual risk management mechanisms adding to the stability of existing or new fuel supply arrangements. Such a discussion would support the recommendations from the Expert Group report and from the World Nuclear Association, which emphasized that existing market mechanisms be reinforced.[13] The "six-state assurance of supply" proposal, developed by the six enrichment-service-supplier states (the United States, France, Germany, Russia, the United Kingdom, and the Netherlands, ranked by volume of nuclear electricity generation), would also certainly support this approach. (For an explanation of these other proposals, see appendix II).

2. The Problem

Nuclear fuel is difficult to commoditize. Even if a stockpile of low-enriched uranium is set aside at one or several locations, the fuel would need to be enriched/blended to the appropriate level and fabricated specifically for a designated nuclear reactor. Experts have said that the time from enrichment to the time of final fuel delivery could take nearly a year, and that is assuming both that there would be no established customers already waiting for fabrication and fuel delivery and that the fuel had been prequalified for the reactor. A likelier scenario might be two years or more in some cases. Thus, supply assurance schemes limited to enriched uranium alone may be necessary but are insufficient.

Nuclear utilities are concerned about the availability of not just enriched uranium but also about the fabrication and transportation of uranium along the whole fuel cycle. Table 1 describes in simplified terms the entire process from uranium ore to electrical electricity power.

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12. As noted in Evan Mills and Eugene Lecomte, *From Risk to Opportunity: How Insurers Can Proactively and Profitably Manage Climate Change*, CERES Report, August 2006. Although current figures have changed, their relative comparison, as follows, generally holds: "The world oil market is US$1.9 trillion/year at current production levels of 76Mbpd and a unit price of $70/bbl price; world electricity market in 2001 was US$1 trillion at 14.8 trillion kWh generation assuming a unit price of US$0.07/kWh; tourism receipts US$434 billion; agriculture US$1.2 trillion (2002); telecommunications US$1.2 trillion (2002); world military expenditures US$770 billion. Source: 2004–2005 Statistical Abstract of the United States."

13. Other recent in-depth commentaries on fuel cycle management issues include Jon B. Wolfsthal, "Assessing Proposals on the International Nuclear Fuel Cycle," Weapons of Mass Destruction Commission (WMDC), No. 11 (Stockholm: WMDC, June 2004); and Harald Müller, "Multilateral Nuclear Fuel Cycle Arrangements," Weapons of Mass Destruction Commission, No. 35 (Stockholm: WMDC, 2005).

Furthermore, fuel fabricators tend to specialize, and alternative fabricators of the fuel assemblies will likely produce lower quality assemblies in terms of optimal performance and may not even be licensed to provide a certain "fuel assembly"(the final product). As fuel markets are expected to tighten, this highlights the importance of utilities managing their commercial and political fuel risks by maintaining fuel stock inventory, using extended lead times for ordering, and assuring (if possible) some alternative sources.

Table 1. From Uranium Ore to Electric Power

Initial Material:	**From:**	**To:**
Ore	Mining	Milling
Yellowcake	Milling	Conversion
Uranium hexafluoride (Hex)	Conversion	Enrichment
Enriched Hex	Enrichment	Fuel fabrication

Sources: World Nuclear Transport Institute, London, United Kingdom. Note that transportation generally occurs across the whole cycle except milling and mining, which are usually co-located.

Demand for greater fuel assurance could cause more countries to seek greater self-sufficiency in nuclear fuel. Although the development of nuclear capabilities for peaceful purposes is apparently permitted under the Nonproliferation Treaty (NPT),[14] it is deemed undesirable for more states to develop the enrichment capability needed for fuel fabrication due to the ensuing nuclear weapons capability. The IAEA, therefore, can try to direct the growth of the enrichment capability in what it would deem more secure ways, and/or it can try to support market mechanisms to reduce concerns over the availability of enriched uranium and nuclear fuel.

3. The Proposal: Integrating Insurance, Reinsurance, and Financial Markets as Part of the Solution

The need for overlapping assurances to provide more supply security is clear—no single solution is sufficient for assuring supply and discouraging enrichment alone. We describe

14. Some scholars argue that the recent interpretation of the Nonproliferation Treaty (NPT) is flawed: that the "right" to develop nuclear capabilities is qualified in Article IV and in the history of the negotiation of the NPT. See, for example, Henry D. Sokolski, Executive Director of the Nonproliferation Policy Education Center, and others, in *The Nuclear Nonproliferation Treaty and Nuclear Energy*, Hearings before the House Subcommittee on International Terrorism and Nonproliferation of the Committee on International Relation, U.S. House of Representatives, 109th Cong. 2nd sess., March 2, 2006, Serial No. 109–148, pp. 5–11.

and evaluate several of the current proposals in appendix II. Several can and should be pursued in tandem. Our proposal, described below in a market context, can be considered complementary to these other proposals.

Large-scale Risks: The Critical Role of Insurance

When we consider the risks involved in the fuel acquisition process (see appendix III), we realize that several other stakeholders—insurers, reinsurers, financial markets—could contribute substantially to moderating the risks should they see a benefit in partnering. So far, none of the current proposals has viewed the insurance industry as a possible partner.

We find this surprising for at least three reasons. First, in most industrialized countries, insurance constitutes an important mechanism by which people and firms manage risk, especially the financial consequences of catastrophes. Indeed, not only has the insurance and reinsurance infrastructure allowed people, firms, and even countries to take controlled risks in their everyday lives—which has resulted in sustainable economic development—but also it has historically played a fundamental role in fostering social and economic recovery in the face of adversity.

Second, insurance constitutes a natural market-mechanism candidate to enhance security: the insurance industry traditionally acts as a nexus between risk assessment, risk mitigation, and risk financing. Insurers and reinsurers are often seen as experts in understanding risk. They are also private sector players who understand how markets operate, a quality most businesses are often reluctant to attribute to any level of government. Including insurers fosters higher levels of trust, together with customer and investor confidence.

Third, if the IAEA decides to look to the private sector to help ensure global fuel supply, what would be a better candidate to start with than what has become one of the largest industries in the world? Though insurance mechanisms are often not well understood, this industry typically generates global revenues even larger than the federal budget of the United States.

We recommend that members of the international community consider forming a mutual insurance entity with the goal of insuring in order to assure fuel supplies. Indeed, the entity could combine assurance of the full fuel cycle (i.e., enrichment, conversion, fabrication, and transportation) of nuclear utilities (public and private) against political interruptions and other risks (e.g., a major natural disaster) and insurance of some of the economic losses associated with temporary fuel supply disruption.

Members of the mutual insurance company would be the countries that need enriched uranium for their nuclear plants (or the owners of these plants). They would pay premiums that the mutual would use to purchase financial coverage via insurance and reinsurance and use to establish a cash reserve. Additional conditions on participation in the mutual would have to be discussed.

Insurers/reinsurers who would participate in the consortium covering this entity would analyze the risks associated with a shortage in the supply of each specific type of fuel and end user. Based on these risk assessments, the entity would charge premiums to the mutual's member countries that use nuclear fuel (Figure 1).[15]

The Use of Supply Options

Both the lack of commoditization of the nuclear fuel market and the insurance companies' extra care in dealing with political risks have been cited as problems for considering the use of financial risk management tools. In addition, and most critical, is a utility's very real need for fuel as opposed to simply financial compensation for the lack of it (or a significant delay in purchasing it). This proposal addresses these concerns.

For this new entity to provide more than just financial coverage, it would use its cash reserve to purchase supply options (assurance of fuel supply). Ideally, member countries would also approve exports in advance without consent rights on the fuel supply options or on the new insurance facility's direct market purchases of electric supply off available grids. Insurance mechanisms, including contract options, could not only prove a useful part of the proposed assurances but also, if desired, provide the framework for managing the development of new supplies.

Nuclear fuel plants are not like batteries in how they provide energy. They do not just go out. There is some limited discretion regarding the timing of fuel assembly change outs and the enrichment levels of the fuel going into the assembly. We believe these are economic decisions that can be compensated if the nuclear system does not operate at optimum capacity. It is also hypothetically possible to ask a customer of a fuel fabricator to forego his place in the fuel fabrication line in exchange for compensation. Money and time are therefore two variables that can be managed and insured.

To limit insurers' and reinsurers' exposure to a level at which they would be comfortable participating, the entity might also benefit from an additional layer of protection through federal backstop from all its IAEA member countries (see Figure 1).[16] The terms of this additional coverage remain to be discussed.

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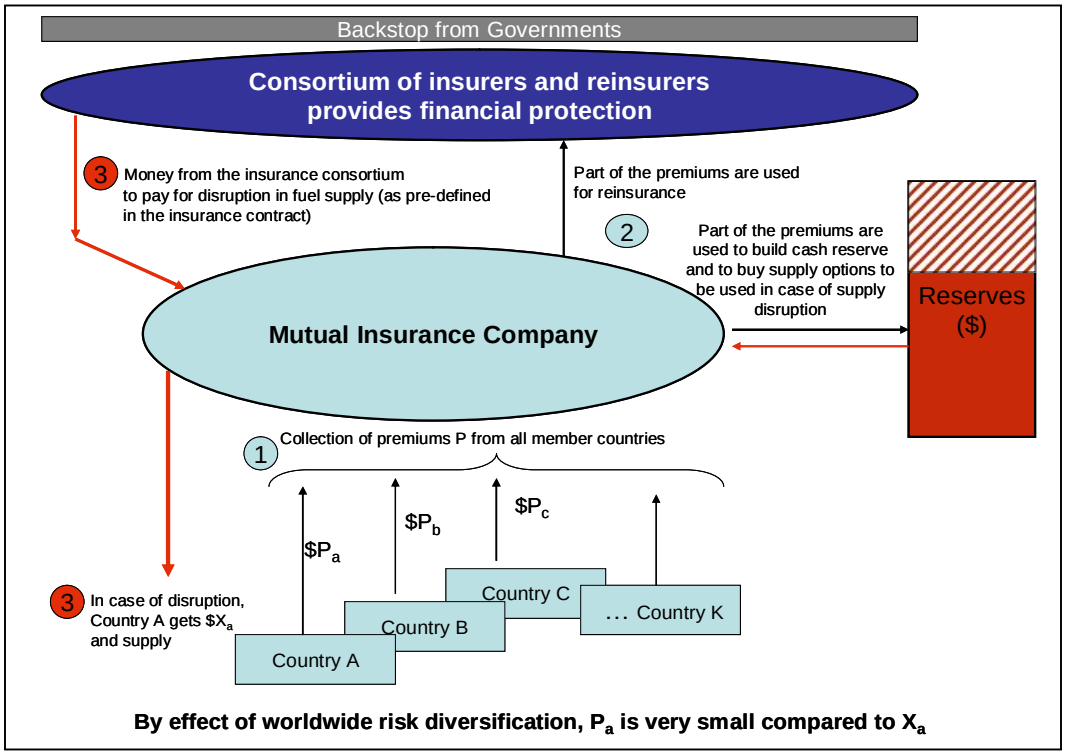
15. IAEA could decide to subsidize rates so that utilities pay based on their supply needs and not on their political risk. By in essence subsidizing rates to those members with higher political risks, the IAEA would induce them to become members and to benefit from the insurance mechanism so that they could stabilize their revenues and operations over time, disregarding untoward events that might affect their capacity to access fuel.

16. In the aftermath of the terrorist attacks on September 11, 2001, reinsurers (who covered nearly two-thirds of the $35 billion insured losses due to the attacks) decided to leave this market. Some have reentered but are only involved at a very limited level. In fact, several OECD countries have developed partnerships between private insurers and reinsurers and their government to cover the economic losses of future terrorist attacks. Insurers and reinsurers typically cover a first layer up to a certain level of industry losses, with the government providing some backstop above that threshold. See Howard Kunreuther and Erwann Michel-Kerjan (2005), "Insurability of (Mega-)Terrorism Risk: Challenges and Perspectives," in OECD, "Terrorism Risk Insurance in OECD Countries," Policy Issues in Insurance, No. 9 (Paris: OECD, July

Figure 1. Insuring to Assure Fuel Supply



The Indemnification Process

If a state found its nuclear fuel prevented from delivery, the following would happen:

- The state would inform the mutual insurance entity.
- The entity would make a determination based on pre-established guidelines (including, for example, the state not being under UN Security Council sanctions) and the nature of interruption in delivery; and this decision would have to be made within an amount of time previously agreed under the insurance contract.[17]
- The insuring entity would exercise its options and work with fuel suppliers, fabricators, and transporters to arrange a timely fuel delivery; and the insurance consortium would compensate the insured and others affected by the replacement for any loss of efficiency beyond a previously agreed amount of loss.

2005), pp. 107–148; see also Erwann Michel-Kerjan and Burkhard Pedell, "How Does the Corporate World Cope with Mega-Terrorism? Puzzling Evidence from Terrorism Insurance Markets," *Journal of Applied Corporate Finance*, Vol. 18, No. 4 (Fall 2006), pp. 61–75.

17. Consideration should be given to the structure of other commodity market programs in designing the approach (e.g., the arbitration program and other aspects of the London Metals Exchange).

A country in the mutual that prohibits delivery of fuel-related goods or services to another country in the mutual (due to political interference) would be temporarily excluded from having its nuclear power guaranteed—both in terms of its provisions of nuclear supplies to others (so others will be less likely to buy from that country) and in terms of receipt of nuclear services from others (so if Country A denies Country B fuel/fuel services, Country A will not have its own receipt of power supplies guaranteed). In short, countries using nuclear fuel–related goods or services for political leverage would be excluded from participation in the mutual pool and from obtaining insurance on supplies to their own utilities.

This arrangement would make the insuring entity's supply ombudsman role financially viable. Suppliers would receive compensation for developing and setting aside some capacity, for bumping out of line other customers (who might be compensated), or for working overtime to fulfill the supply need. The entity would define compensation schemes in advance so every country covered by the consortium knows exactly what it gets for any delay in access to supply and the role the insurance consortium plays in facilitating the supply.

If the IAEA were to support the insurance entity, it could require all members to have some political risk insurance on its nuclear fuel—perhaps based on the amount of enriched uranium used—and then no "adverse selection" would result. That is, no state would gain an asymmetric knowledge advantage in which they would be buying more insurance knowing that they needed it because their suppliers were about to cut them off. Instead, the IAEA would, in essence, insurance tax all states for the privilege of buying enriched uranium. This would help fund the insurance facility's purchase of options and of reinsurance.

Our insurance facility proposal is most beneficial because of its universal applicability: states, including the major enrichment states, could recognize their dependence on international markets for different aspects of their fuel, from ore to fabrication, and elect to participate. This proposal would cover the full supply chain, not just enrichment, and could provide financial support to the assurance-of-supply framework proposed by the World Nuclear Association (WNA) and others.

Under this insurance entity, a state could be less likely to use its nuclear fuel supplies for leverage against others—as this would not only cause it to lose its own guarantees but also would find its actions with much less effect. Including private insurers and reinsurers as part of the mutual equation also removes some of the politics—the mutual facility would automatically supply a utility when called upon unless *force majeure* (e.g., the UN Security Council) prohibited it from doing so. In addition, this facility could also help foster private markets by using public trading platforms to make uranium purchases—thereby helping to further commoditize that market.

4. Is This Doable?

In this section we question the feasibility of this proposal by considering the views of different interested stakeholders.

From the Insurance Companies' Perspective

Traditionally, insurance companies are most comfortable dealing with measurable risks with knowable probabilities (based on a large number of cases and long experience). Insurers, however, do also cover some risks associated with infrequent, costly events such as major natural disasters and terrorism. But often they do that in collaboration with local or national governments that cover part of the risk or provide some type of backstop for the extreme portion of it. Several OECD countries have such a collaborative mechanism in place for terrorism insurance in the post September 11, 2001, environment. Insurers and reinsurers, who would typically refuse alone to cover catastrophic risks that could seriously affect their capital or even lead them to bankruptcy, see their exposure limited to a somewhat manageable size through this collaboration with the public sector.

Likewise, the 143 IAEA member states (as of December 2006) could backstop the insurance/reinsurance consortium (see Figure 1), allowing each state to cover a limited portion of the whole coverage. The benefit then of involving the insurers includes some initial reinsurance coverage and better program management with third-party administrators who are familiar with administering what is in essence business-interruption insurance. We also believe it would be important for the consortium and mutual insurance facility to be incorporated on neutral territory. Furthermore, covering a large number of independent risks located far from one another reduces the variance of the loss. In this case, the large and growing number of countries with nuclear facilities would increase risk diversification and reduce the exposures of participating insurers. This proposal has some public-private collaboration similarities with the way nuclear liability insurance works in the United States, though on an international scale rather than national.[18]

18. The 1957-enacted Price-Anderson Act ensures that funds would be available for at least a portion of the damages suffered by the public in the event of an incident at a U.S. nuclear power plant. To operate a nuclear power plant, the owner must obtain a license from Nuclear Regulatory Commission and meet its regulatory requirements, including those for liability insurance established under the Price-Anderson Act. Each licensee must have primary insurance coverage equal to the maximum amount of liability insurance available from private sources—currently $300 million—to settle any such claims against it. In the event of an accident at any plant where liability claims exceed the $300 million primary insurance coverage, the act also requires licensees for all plants to pay retrospective premiums. These payments could amount to a maximum of $95.8 million for each of a licensee's plants per incident. If claims for an incident exceed this approximately $10 billion currently available in primary insurance and retrospective premiums, NRC may request additional funds from the Congress. Government Accountability Office (GAO), *Nuclear Regulation: NRC's Liability Insurance Requirements for Nuclear Power Plants Owned by Limited Liability Companies* (Washington, D.C.: GAO, May, 2004).

The question, of course, is whether a critical mass of insurers and reinsurers with enough capital would join the consortium. Our discussions over the past few months with leading companies in this industry indicate that they would be willing to consider this option as soon as the terms of their involvement are clearly defined and they see a high enough return on equity.

From the Suppliers' Perspective

The companies involved—although many are government owned or subsidized—would want to be compensated for maintaining any excess capacity or for having to run extra shifts to fill unexpected supply orders. For example, both Areva (in France with partners) and USEC (whose subsidiary United States Enrichment Corporation also operates a gaseous diffusion enrichment plant) are building new centrifuge enrichment plants that could leave extra capacity.[19]

These enrichers or any supplier could participate and sell options, so the entity need not support only existing major suppliers—in other words, new market entrants are possible. However, options might only be purchased from countries that preapproved the exports resulting from the exercise of insurance entity supply options (akin to the United Kingdom's Performance Bond approach—see appendix II) and that met other criteria the entity would define. When the mutual facility needed to supply a country in need, it would exercise these options. Japan, India, and Brazil, among others, could all potentially sell enriched uranium options at some point, if they met the conditions for participation.[20] However, it would be up to the entity (or IAEA) to decide how to apportion (or restrict) option purchases. Whether suppliers could be compensated sufficiently to make this a commercially attractive proposal would need to be assessed.

If the United States, France, Germany, Russia, the United Kingdom, and the Netherlands implement their proposed "six-state assurance of supply" (see appendix II), a framework would be in place to facilitate the purchase of supply options on the enriched uranium portion of the fuel from suppliers in these countries. Little excess capacity would likely need to be maintained to fulfill enrichment needs. If one or two enrichers are prohibited from supplying another country, fuel enrichment orders will get swapped around—such as is already done today in flag-swapping on international fuel shipments. Also, if the uranium market increases in depth and transparency, the insurance facility could purchase uranium through an exchange and not elect to exercise its uranium supply options; the facility could base that decision on pricing and risk and the possible differing transportation costs.

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19. The new enrichment plants are expected to allow modular additions for expanded capacity. Also, these companies could consider mothballing rather than disassembling the older, albeit much more expensive to run, plants.

20. Although the enriched uranium from these new suppliers would be more expensive, this insurance entity and the international community must consider expanding the number of or nature of suppliers and consider directing the growth of supply. For example, the insurance facility might purchase enriched uranium options only from suppliers that met certain conditions, such as being multinational.

From IAEA and Member States' Perspective

The IAEA and its members should view the insurance facility positively. Supplies would be more secure through the enhanced working of market mechanisms and the pooling of risks. The financial and legal transactions required would likely be less than under any of the other assurance-of-supply proposals. Some member states might not feel that they need the insurance and thus might not want to be covered by the consortium. However, even wealthy states seem to show interest in this proposal because they are dependent on the international community for obtaining different nuclear fuel products and services.[21] The program would have to be attractive enough to induce cooperation; states would have to understand that having universal coverage would potentially not only decrease proliferation but also assure their interests.[22]

To become members of the insured pool, states would have to meet certain insurer guidelines, such as being free from Security Council sanctions. As it might be difficult to set the standard very high and still retain interest in the insurance product, the appropriate standards should be surveyed among the potential participants including the reinsurers. That survey process would help determine if conditions should include (among others): having full safeguards and the Additional Protocol in place, as well as possibly being in full compliance with other international obligations such as UNSCR 1540, which criminalizes nonstate actors' possession, use and delivery of weapons of mass destruction and their delivery. Recent proposals in the voluntary Nuclear Suppliers Group to block trade with countries that do not have the Additional Protocol in place have not been accepted. United Nations Secretary-General Kofi Annan's High Level Panel on Threats, Challenges and Change suggested simply that supplies be guaranteed "as long as there were no breach of safeguard or inspection procedures at the facilities in question."[23]

One important question is to what extent membership in the pool would be conditioned on behaviors regarding enrichment. Most of the other assurance proposals restrict assurances of enriched uranium to states not enriching or about to enrich uranium or to reprocess spent fuel.

Our proposal would not preclude states from enriching uranium. If states desire to retain membership in the pool, however, the entity could encourage them to enrich *only* within permitted guidelines—which would reflect the insurers' and reinsurers' risk assessment of whether the state might face political sanctions, natural disasters, or other types of risks that the entity would have to cover.[24] These guidelines could include

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21. "Energy: Energy Diary/From Missiles to Megawatts," *Wall Street Journal*, September 12, 2006, p. A14.
22. With a voluntary program, penalties could be imposed for delayed insurance buy-ins.
23. United Nations, *A More Secure World*.
24. As insurance companies do/can not always base premiums on direct risk assessments and as the purpose of this insurance scheme is to encourage countries not only to be better assured of fuel supplies but also to act in a certain way and to enrich only in a limited, controlled fashion, having these guidelines in place—as negotiated in IAEA among member states—would be desirable.

allowing new enrichment subject to establishing multinational ownership of facilities, among other possible conditions. Members who currently enrich or who start enriching uranium might need to meet guideline requirements such as moving their enrichment facilities toward multinational or international ownership within a specific timeframe. This would support, for example, Russia's initiative to develop an international uranium enrichment center in Siberia.

The perceived benefits of joining the mutual insurance pool should outweigh the possible costs of having to limit one's behaviors slightly. Although the goal is assurance of supply, the reason for providing such assurances cannot be overlooked. The benefits of membership in the pool must balance the conditions for membership. An understanding of the prospective participants' interests is needed in order to craft an attractive product (see appendix V). To further assure states that this mechanism is apolitical, the mutual insurer's actions would only be overruled by a unanimous vote of the permanent members of the Security Council and/or a majority or two-thirds of the full council, with the vote taking place within a prespecified time frame of notification.

Can this Control Enrichment?

As this covers the full fuel supply cycle, not just enrichment, it would provide more assurance to countries needing fuel. Having a mutual mechanism in place that includes the private industry and a broad range of suppliers also provides more assurance by restricting IAEA and major state control of the insurance process, thereby depoliticizing it. Including private insurers provides added contract security as well as in terms of the tort system. The insurance consortium might then want to offer a full range of supply disruption guarantees, including over certain commercial risks, which appear to be a growing concern. Thus, states should find they have good incentive to participate and will comply with the membership guidelines.

Summary

The insurance plan encourages reliance on international markets and established mutual insurance frameworks. It elaborates what the World Nuclear Association calls "level 2 guarantees." The formation of a mutual insurance company is a way to codify with a quasi-private market mechanism the "six-state assurance of supply." The insurance plan could be available to all countries (including the six states themselves) that fit the prespecified requirements—not just those without enrichment technologies—in order to broaden its appeal. It covers the full front end of the fuel cycle—not only providing guarantees on natural or low enriched uranium but also its fabrication and transportation. It is consistent with the recommendations of the IAEA Expert Group's report, "Multilateral Approaches to the Nuclear Fuel Cycle," which included international supply guarantees with IAEA participation, but not necessarily with IAEA as administrator of a fuel bank. It is also consistent with the EU Common Position for 2005

Nonproliferation Treaty Review Conference calling for guarantees of access to nuclear fuel and services.

The insurance plan does not prohibit the establishment of multinational joint ventures, through either the redesign of existing or expanded facilities or the construction of new facilities. In this regard, a country could still encourage other countries to join in its venture or to join with other countries if they wanted to gain the advantage of an alliance and were willing to accept any liabilities therein. Such ventures, however, would be undertaken for financial reasons and not necessarily solely for guaranty of supply—which would be provided by the market and insurance mechanisms.

5. Complementary Mechanisms and Other Considerations

In this section we briefly highlight other solutions whose development could help facilitate the implementation of the proposal and its operation. We also note other factors that need consideration.

Performance Bonds

Another way to provide some coverage is through political risk insurance on group performance bonds. A performance bond is a financial tool used to guarantee that, in the event of a contractor's default, funds are available to guarantee the proper delivery of a good or services.[25] Applied to fuel supply, a group of suppliers would provide a proof of bond that would provide insurance coverage if one of its members could/would not fulfill a supply contract. In this case, the bond is exercised and the insurers make payments directly to the other suppliers who would need to divert some of their supplies to fulfill the contract. This would compensate the other suppliers for diverting their supplies and potentially for paying their regular customers for delays as the suppliers performed some of the work one of its members could not perform. This could also make the bonded suppliers more attractive as sources for those purchasing the fuel but would not necessarily eliminate the political risks. Bonding with political risk insurance coverage could be explored for the “six-state assurance of supply” proposal.

25. For example, performance bonds are often used in the construction of large real-estate or technology complexes. To illustrate the traditional performance bond model, imagine a city ordering the construction of a large infrastructure project such as an airport. From the city’s perspective, the insolvency of a contractor during the construction contract will most likely result in delayed project completion. It is common to require contractors to provide proof of a bond (from a bank or insurance company) so that the city can recover damages it may sustain as a result of the contractor's default up to a stipulated limit, often the estimated cost of construction for the infrastructure. The group performance bond described here, however, could be arranged so that the individual members of the group were mutually insured and payments could be made to a member of the group to provide enriched uranium. The point is that insurance products can be structured in many different ways.

Uranium as a Commodity

Another longer-term approach is to develop enriched uranium into a commodity product. In order for a good to be a commodity, it has to be available as a standard product and bought in sufficient amounts to form a stable market. This might be possible at some point with enriched uranium products. If fuel is a commodity, some might worry about fluctuations in prices but not as much about the availability of supplies. Furthermore, futures markets could cover price fluctuations. IAEA should consider the benefits of helping to establish a commodity market. (See appendix IV).

If the commodity market is robust,[26] the mutual insuring entity would not need to depend solely on supply options but could look to direct market purchases to fulfill its insurance obligations. In a developed market, the nuclear utility could also choose to access enriched uranium supply directly in the market if one state imposes sanctions upon it, or it might elect to use its insurance to fulfill other needs (such as fuel fabrication which is not likely to be able to be commoditized). The sanctioned utility/country could elect to use its insurance to regain supply only when that is more economical than direct market purchases.

Impact of New Technology/Developments

If enrichment technology advances (e.g., laser enrichment) so that costs decline substantially, it might become harder to control the enrichment market. We believe, however, that if the proposed program were structured to provide assurances across the full fuel cycle and attendant transportation needs, and if it were only open to nuclear power plants in those countries whose enrichment capabilities met preapproved insurer/IAEA guidelines, then there would still be some incentive for countries to stay within the insurance regime.

In making nuclear power more attractive through supply assurances and thereby supporting more nuclear development, IAEA will need to consider the security of the spent fuel and ways to make the back end of the fuel cycle more proliferation resistant. It should support structuring agreements for supply assurances with the possibility in mind of adding agreements covering spent fuel (e.g., requiring leasing vs. ownership), perhaps as steps in a process toward multinationalization of the fuel supply.

6. Conclusions

Nuclear power is expanding and more and more countries want to be assured of sufficient fuel supplies. As we discussed, however, although assurance of supply will reduce one

26. Nymex, owner of the largest energy exchange, the New York Mercantile Exchange, recently had a very successful public offering. See Kevin Morrison and Anuj Gangahar, "Blistering Debut for Nymex as Shares Soar," *Financial Times*, November 17, 2006, p. 1.

incentive for broadened enrichment (which can subsequently be used to build up nuclear weapons), it will not reduce all incentives. It also does not address the problem with potential proliferation from the back end of the fuel cycle. To reduce the desire to convert nuclear materials to weapons use, nuclear weapons should become not a source of prestige but of revilement; to move in that direction, the nuclear weapon states must reverse their nuclear weapons–dependent policies.

Furthermore, if the underlying concern is proliferation of nuclear material for nonpeaceful uses, then efforts need to be directed toward strengthening the safeguards regime. As the IAEA Expert Group noted in 2005, "The primary technical barriers against proliferation remain the effective and universal implementation of IAEA safeguards under comprehensive safeguards agreements and additional protocols, and effective export controls. Both must be as strong as possible on their own merits. MNAs (multilateral nuclear approaches) will be complementary mechanisms for strengthening the existing non-proliferation regime."[27]

Any new approach should strengthen the safeguards regime by requiring full participation in safeguards by any states that partake of assurances (giving or getting) or that are involved in other MNAs.

The initiative proposed here, which consists of working with experts in insurance/finance to establish an international mutual pool with insurance and reinsurance layers provided by the private industry and a back-up by a large number of countries, is an appealing way for IAEA and the international community to tackle the problem of fuel supply assurance. Although we expect this mechanism to provide the assurances needed to forestall enrichment in countries both considering nuclear power generation for the first time and desiring fuel security, the proposed mechanism may well not dissuade the states already looking to invest in enrichment capabilities for reasons of prestige, power, or possible nuclear breakout. It also does not address states interested in nuclear propulsion, an important but much smaller field of interest.

The proposal, however, can be crafted to influence the future nuclear regime by defining who is allowed to participate in the mutual in such a way as to encourage states to act responsibly. In a way, this is not unprecedented but common practice. Insurance companies often define risky and responsible behaviors and price their coverage accordingly, or exclude certain coverage altogether. The mutual would define these behaviors among those covered and could likely be even more strict in its assessments than the IAEA. Furthermore, if the mutual evaluates the establishment of a nuclear enrichment capability, it could define the terms of future enrichment by considering what the IAEA deems acceptable. This is logical because a country undertaking enrichment outside the bounds of standard accepted behavior runs a greater risk of being sanctioned; as a result, its peers in the mutual might not want it included or they could require stronger conditions. Therefore an explicit vision of acceptable future enrichment facilities (multinational, safeguarded, and so on) might be devised as part of this insurance mechanism.

27. IAEA, "Multilateral Approaches to the Nuclear Fuel Cycle," p. 11.

The final question is: If this is such a good idea, why isn't the market already doing it? We believe that because of the nature of this proposal, certain players (such as the insurers (supply side) and the nuclear utilities/states (demand side)) must group together to form a sufficient *critical mass* to make the proposal work. There is no logical individual player to lead the effort alone, especially given the necessary upfront costs in time and consultative fees to further this program. In addition, private markets will not take this forward without state and international organization involvement—states need to provide new contractual approvals for exports; certain trade organizations need to allow long term contracting; state subsidies may be needed to attractively price the product; and states must provide the ultimate backstopping to the insurance mechanism.

In other words, for the plan to succeed, international collaboration is needed not only between countries but also between the public and private sectors. This will take concerted leadership. It is also very likely that those first to lead could be the first to profit from the establishment of this mechanism—either financially (in the case of private insurers that would help structure then underwrite the program or utilities that would likewise help structure then receive the risk mitigation benefits) or politically (in the case of countries that could help shape the mechanism to its interests).

7. Possible Next Steps toward Implementation

Here we offer the following timeline to study the feasibility of this proposal.

Six to Twelve Months

To explore this concept further, the IAEA, possibly in partnership with the World Energy Council (WEC) and other interested parties, should establish an initial consultative group/task force to ascertain current and potential nuclear fuel buyer interest in the forms of assurances of supply. Discussions have been supplier driven until now rather than demand driven. Buy-in from the ultimate users of nuclear fuel is needed.

The group could be co-chaired by a third party business leader and by an IAEA/WEC representative. Included in the group would be those with expertise in public-private insurance initiatives and nuclear security, and large insurers and reinsurers, who are interested in developing the concept—such as existing nuclear facilities and large insurers, reinsurers, investors and trade associations (e.g., World Energy Council, World Nuclear Association). The group could canvass buyers on various proposals not limited to this proposal as its attractiveness is impacted by the other assurances that might become available in the market to complement or substitute for ours.

The task force should determine demand for the suggested mechanism. It should consult fuel buyers in the six states with enrichment services, as we have heard concerns

over nuclear supply commercial and political risks in these states.[28] A mechanism that the supplier states would also be interested in using for their nuclear utilities would have the most impact and could lead to the development of assurance mechanisms that other countries could buy into. Representatives of present or potential international fuel purchasers in other countries (Argentina, Brazil, China, Egypt, Korea, and South Africa, among others) should also be heard.

The task force should more systematically ascertain the interest of those needed to supply the services. Insurance specialists would need to explore and advise on the more specific aspects of this mutual captive insurance program. Frameworks for establishing a nonprofit mutual already exist both within the nuclear industry and in P&I clubs, although additional insurance expertise would be needed to expand the traditional product base to secondary supply interruption insurance (which this proposal encompasses) and political risks. The possibility of purchasing supply options should be discussed with nuclear fuel suppliers—including future potential suppliers, such as Japan. Although some have indicated to us a willingness to issue supply options, and indeed long-term contracts with supply options have their options informally traded, the pricing range of these options, the amounts supplied, and the time frames of the options need to be discussed in greater detail. For the program to work well, all new nuclear facilities would need to have multiple licensed fuel providers. The fuel-providing states, perhaps by treaty, would have to agree not to take added recriminatory actions against others for obeying certain prearranged IAEA dictates.

Finally, the task force should help to "set the bar" for participation. Key players need to discuss questions of eligibility restrictions for inclusion in the pool and how to apportion the option purchases.[29] Separately, roundtable discussions of the potential for the development of an enriched uranium commodities market should also be undertaken with full consideration of its benefits and possible drawbacks. Innovative market developers, nuclear fuel specialists as well as experts in catastrophic risk management, and international organizations, should all participate in these discussions.30

28. Including these states as receivers of assurances would serve two purposes: (1) to assure good provision of services as they would be structuring the service also for themselves, and (2) to allow for a nonthreatening mechanism to resolve any future differences.

29. For example, some possible conditions have been detailed in Pierre Goldschmidt, "The Proliferation Challenge of the Nuclear Fuel Cycle in Non-Nuclear Weapon States" (Paris: Institut Français des Relations Internationales, April 26, 2004), http://www.iaea.org/NewsCenter/Statements/DDGs/2004/goldschmidt26042004.html.

30. We would like to thank the London-based Commonwealth Disaster Management Agency (CDMA) for its advice on our development of this concept and note with pleasure that CDMA indicates it is now taking steps to put together a working group to further explore an insurance product along the lines discussed in this paper.

Following Six Months

If the initial consultative group receives positive feedback on this proposal, a full feasibility study should be commissioned that includes legal and financial specialists to lay out the next steps, including any enabling legislation that countries or organizations would need to enact in order to participate. IAEA and/or WEC could host this study, and the countries interested in establishing the international mutual could lead it.

Appendices

Appendix I. World Nuclear Power Reactors 2005–2007 and Uranium Requirements

January 2007											
	NUCLEAR ELECTRICITY GENERATION 2005		REACTORS OPERABLE Jan 2007		REACTORS under CONSTRUCTION Jan 2007		REACTORS PLANNED Jan 2007		REACTORS PROPOSED Jan 2007		URANIUM REQUIRED 2007
	billion kWh[31]	% e	No.	MWe*	No.	MWe*	No.	MWe*	No.	MWe*	tonnes U
Argentina	6.4	6.9	2	935	1	692	0	0	1	700	135
Armenia	2.5	43	1	376	0	0	0	0	1	1000	51
Belgium	45.3	56	7	5728	0	0	0	0	0	0	1079
Brazil	9.9	2.5	2	1901	0	0	1	1245	4	4000	338
Bulgaria	17.3	44	2	1906	0	0	2	1900	0	0	255
Canada	86.8	15	18	12595	2	1540	2	2000	0	0	1836
China	50.3	2.0	10	7587	5	4170	13	12920	50	35880	1454
Czech Republic	23.3	31	6	3472	0	0	0	0	2	1900	550
Egypt	0	0	0	0	0	0	0	0	1	600	0
Finland	22.3	33	4	2696	1	1600	0	0	0	0	472
France	**430.9**	**79**	**59**	**63473**	**0**	**0**	**1**	**1630**	**1**	**1600**	**10368**
Germany	**154.6**	**31**	**17**	**20303**	**0**	**0**	**0**	**0**	**0**	**0**	**3486**
Hungary	13.0	37	4	1773	0	0	0	0	0	0	254
India	15.7	2.8	16	3577	7	3178	4	2800	15	11100	491
Indonesia	0	0	0	0	0	0	0	0	4	4000	0
Iran	0	0	0	0	1	915	2	1900	3	2850	143
Israel	0	0	0	0	0	0	0	0	1	1200	0
Japan	280.7	29	55	47700	2	2285	11	14945	1	1100	8872
Kazakhstan	0	0	0	0	0	0	0	0	1	300	0
Korea DPR (North)	0	0	0	0	0	0	1	950	0	0	0
Korea RO (South)	139.3	45	20	17533	1	950	7	8250	0	0	3037
Lithuania	10.3	70	1	1185	0	0	0	0	1	1000	134
Mexico	10.8	5.0	2	1310	0	0	0	0	2	2000	257
Netherlands	**3.8**	**3.9**	**1**	**485**	**0**	**0**	**0**	**0**	**0**	**0**	**112**
Pakistan	1.9	2.8	2	400	1	300	2	600	2	2000	64
Romania	5.1	8.6	1	655	1	655	0	0	3	1995	92
Russia	**137.3**	**16**	**31**	**21743**	**3**	**2650**	**8**	**9600**	**18**	**21600**	**3777**
Slovakia	16.3	56	5	2064	0	0	2	840	0	0	299
Slovenia	5.6	42	1	696	0	0	0	0	1	1000	145
South Africa	12.2	5.5	2	1842	0	0	1	165	24	4000	332
Spain	54.7	20	8	7442	0	0	0	0	0	0	1473
Sweden	69.5	45	10	8975	0	0	0	0	0	0	1468
Switzerland	22.1	32	5	3220	0	0	0	0	0	0	575
Turkey	0	0	0	0	0	0	3	4500	0	0	0

31. Kilowatt-hour
* Megawatt net (electrical as distinct from thermal)

January 2007											
	NUCLEAR ELECTRICITY GENERATION 2005		REACTORS OPERABLE Jan 2007		REACTORS under CONSTRUCTION Jan 2007		REACTORS PLANNED Jan 2007		REACTORS PROPOSED Jan 2007		URANIUM REQUIRED 2007
	billion kWh[31]	% e	No.	MWe*	No.	MWe*	No.	MWe*	No.	MWe*	tonnes U
Ukraine	83.3	49	15	13168	0	0	2	1900	0	0	2003
United Kingdom	**75.2**	**20**	**19**	**10982**	**0**	**0**	**0**	**0**	**0**	**0**	**2021**
USA	**780.5**	**19**	**103**	**98254**	**1**	**1200**	**2**	**2716**	**21**	**24000**	**20050**
Vietnam	0	0	0	0	0	0	0	0	2	2000	0
WORLD[32]	**2626**	**16**	**435**	**368,860**	**28**	**22,735**	**64**	**68,861**	**158**	**124,225**	**66,529[33]**
	billion kWh	% e	No.	MWe	No.	MWe	No.	MWe	No.	MWe	tonnes U
	NUCLEAR ELECTRICITY GENERATION 2005		REACTORS OPERATING[34]		REACTORS BUILDING[35]		ON ORDER or PLANNED[36]		PROPOSED[37]		URANIUM REQUIRED

Sources: *World Nuclear Association, International Atomic Energy Agency*

Note: Highlighted in grey are the six major enrichment-service-supplier states (the United States, France, Germany, Russia, the United Kingdom, and the Netherlands).

32. The world total includes 6 reactors on Taiwan with a combined capacity of 4884 MWe, which generated a total of 38.4 billion kWh in 2005 (accounting for 20% of Taiwan's total electricity generation). Taiwan has two reactors under construction with a combined capacity of 2600 MWe.
33. Equivalent to 78,458 t U_3O_8
34. Connected to the grid.
35. First concrete for reactor poured, or major refurbishment under way.
36. Approvals and funding in place, or construction well advanced but suspended indefinitely.
37. Clear intention but still without funding and/or approvals.

Appendix II. Other Proposals under Consideration

Several fuel supply assurance proposals are currently receiving attention on the international scene.[38] Here we review some of them and assess their relative pros and cons with letter grades ("A" being the best) for (1) their feasibility, and (2) their ability to control enrichment. A more thorough evaluation would require in-depth analyses which are not the purpose of the study here. Nevertheless, we believe this overview is useful as a first-level benchmark.

Proposals that Focus on Enrichment

The following proposals focus on assuring and controlling enrichment.

Multilateral Fuel Bank(s)

Multilateral fuel banks are one way of economically reducing the risk associated with fuel access.[39] In order to have a bank or fuel service company, a country must offer to host and possibly to lead it. Russia supports an international enrichment center as a joint stock or venture company based in Russia and operating under Russian laws. Multilateral fuel banks and fuel service companies that could guarantee fuel to their member/owners may appear attractive to some richer states that can afford the investment in a joint venture.

In reality, most countries can barely if at all afford to finance their reactor investments, let alone a large investment in a separate fuel company. If the developer of a multilateral fuel bank wants countries that cannot afford the upfront investment to "buy in" then he would have to offer a fuel contract entitling a country to eventual and certain purchase rights or to a cooperative interest in the company. Options instruments could develop both for the fuel and services and for ownership in the company.

A country or utility would only decide to invest in a fuel service bank if it deems the company is both reliable enough to provide fuel and services and efficient enough to make stock options profitable, if the company were to be a commercial enterprise and not a cooperative established for the purpose of fuel assurances alone. The investing country would still confront some political risk, however, if the fuel service facility were operated on the sovereign territory of one country and not subject to special contractual laws.

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38. For another good overview, see Oliver Meier, "News Analysis: The Growing Nuclear Fuel Cycle Debate," *Arms Control Today*, November 2006, http://www.armscontrol.org/act/2006_11/NAFuel.asp.
39. The IAEA report on multilateral fuel banks includes spent fuel storage, as does the Russian proposal. The Russian proposal is considered here within the multilateral fuel bank concept. This paper concentrates on supply, given that the purpose of the IAEA Special Event conference was to concentrate on supply assurances as a first step in moving toward a comprehensive approach.

The political risk incentive to invest is based on the belief that the host country is an unwavering ally fully capable of arranging all services and transport and that the partial ownership by the utility/country entitles it to special rights. Designating the land of this or any international facility as "international territory" with special treaty rights (per the German proposal) should help mitigate some political risk but certainly not all.

Doability = C- or B- ("C-" because this project would require large long-term investments in/by new countries; "B-" because possibly Russia can attempt this on its own and see who joins; many are still wary of Russia's nuclear industry after Chernobyl and worry about Russian efficiency and laws—despite some good reports on Russian service.)

Controlling Enrichment = A- or C ("A-" if several fuel banks are established outside existing supplier states. "C" because only Russia is moving forward on this now; if it works, it will attract some states but not those with little faith in Russian technology or Russia. Furthermore, the promised training of the foreign nuclear scientists from cooperating countries—albeit an IAEA goal—could lead to dangerous technology transfers.)

Six-State Assurance of Supply

The United States, France, Germany, Russia, United Kingdom, and the Netherlands have suggested an assurance of enriched uranium supply so that if one supplier's delivery is disrupted due to political reasons unrelated to proliferation concerns, the remaining enrichers would collectively provide a substitute source of supply at market rates pending resolution of the disruption. It is unclear to what extent countries would need to forego enrichment and reprocessing to be eligible for the assurances. Some in the international community suggest that the major enrichers—Rosatom (Russia), Areva/Eurodif (France), Urenco (Germany, the Netherlands, and the United Kingdom), USEC (United States) — should set aside some enriched fuel to backup the assurance. Indeed, the United States pledged 17 metric tons of HEU to help support supply assurances to states that foreswear enrichment and reprocessing; this HEU can be blended down to 290 metric tons of LEU, enough to refuel 10 reactor cores or fuel about 6.5 new cores.

Others have discounted such assurances as the "haves" still trying to block out the "have nots" and point to the lack of full supply cycle assurance. This is further complicated in that USEC is a private company and Areva may be partially privatized. The longer-term U.S. plan is the Global Nuclear Energy Partnership, whereby the United States would promote new reactor technologies and assure the supply and management of fuel.

Doability = B- (Agreement on the details between the states and the companies will be hard to achieve—but not impossible.)

Controlling Enrichment = B (States should feel somewhat assured of getting enriched uranium but could still be cut off in other ways. In addition, the U.S. pledge is

qualified because under U.S. law, the enriched uranium must be under U.S. control in that the United States retains "consent rights" over its use.)

IAEA Fuel Bank

IAEA could also fund a growing stockpile of enriched uranium that it would release under predetermined conditions involving a country's being cut off from enrichment for political but not for proliferation reasons.[40] To establish this, NTI (with the backing of investor/philanthropist Warren Buffett) has pledged $50 million on the condition that IAEA raise another $100 million in cash or its equivalent in low-enriched uranium and establish the mechanism for the reserve over the next two years. This reserve's location has not been defined. Some mention the possibility of Kazakhstan—a country that has large reserves of uranium ore.

Doability = B (This proposal has momentum. If the IAEA shows aggressive leadership and receives U.S. support—including U.S. congressional approval—for the transfer of ownership of some U.S.-converted HEU (or for its sale and donation), or gets added funding from other donors, then this could be established.)

Controlling Enrichment = B+ (States would also have to trust IAEA capability to deliver both in political and business terms. The control of the IAEA board is the underlying issue, but this scheme could be depoliticized with the establishment of certain automatic mechanisms overseen by outside parties. Again, however, this proposal does not consider the full fuel cycle.)

IAEA Enrichment Plant

Germany is developing a proposal that would have IAEA operate an enrichment facility in an extraterritorial area provided by a country. Countries that funded the enrichment plant would gain the right to acquire fuel. The details of the proposal are not yet clear.

Other Proposals

The above proposals focus on market intervention at only one very discrete point of concern to IAEA—that is, enrichment. They might be insufficient if the IAEA wants to support the development of nuclear power and take care of member concerns over political interference. A problem arises under any assurance scenario if, for example, no fuel fabricator can or will make and arrange transport for the fuel assembly. Political interference could disrupt any part of the fuel supply—not just the enrichment process. This will lead states to discount the value of any enriched fuel bank.

40. See Tariq Rauf, interview by John Bohannon, in "Treading the Nuclear Fuel Cycle Minefield," *Science*, Vol. 315, No. 5813 (February 2007), p. 791.

Therefore, to give states fuel assurances, the assurance must be credible and potentially available throughout the whole cycle of fuel acquisition. The best way to provide assurance is by adding security to existing dependencies and by providing for alternative suppliers within the system. In this regard, the United Kingdom's proposal for bonding and the World Nuclear Association's layered approach—both explained below—are important supports and explications of the overall frameworks outlined above.

Bonding (UK government proposal)

Supplier states should provide preapproved export assurances to states that enforce Comprehensive Safeguard Agreements with the Additional Protocol under the condition that IAEA certifies that all material use is for peaceful purposes; that recipient states agree not to engage in, research or develop enrichment or reprocessing; and that states enforce physical protection levels of their nuclear materials in accordance with IAEA guidelines. This would require the establishment of a standard model legal agreement among suppliers, the IAEA, and recipient states working under international laws, treaties and undertakings (e.g., including Nuclear Suppliers Group guidelines).

Doability = B (Lawyers must determine whether there is an instrument that could be developed to operate within existing agreements and national laws or to supersede them. Major changes to treaty instruments and national legislation would significantly lower the doability factor. Also, it remains to be seen whether supplier states' legislatures—if they need to change domestic legislation—would agree to cede such clear controls over a range of goods to IAEA.)

Controlling Enrichment = B+ (States would also have to trust IAEA capability to deliver only apolitical assessments and not the product.)

Multilayered Approach (WNA)

The World Nuclear Association supports multilateral, multilayered supply guarantees.[41] At the core is the existing market mechanism, which has generally worked well commercially until now. At the second level is a collective guarantee of supply from enrichers supported through government/IAEA commitments, with a standard backup supply clause in contracts among eligible parties. The third level would be actual stocks of enriched uranium product. The WNA notes that enrichers must be compensated for providing guarantees and that the guarantees apply only to political interference not commercial problems and that enrichment countries must have formal commitments to allow for contract execution.

41. World Nuclear Association, *WNA Report: Ensuring Security of Supply in the International Nuclear Fuel Cycle* (London: WNA, May 2006), http://www.world-nuclear.org/reference/pdf/security.pdf.

Doability = *C+* (This approach assumes the collective doability risks of both the supply assurances and fuel bank schemes. To the extent they are possible, this overarching plan is.)

Controlling Enrichment = *B+* (As in the bonding proposal, states would have to trust IAEA to be apolitical.)

Conclusion

In addition to these proposals, which are largely mutually reinforcing, the six major enriching states should consider being open to others eventually joining the enrichment club—with strict conditions for providing mutual guarantees. Also, the IAEA or WNA should explore whether another country besides Russia wants to establish a multinational enrichment facility. The IAEA might locate small fuel banks at various enrichment facilities or buy supply options from them. Clear criteria should define which efforts the international community supports. Such criteria could include, among other things: full safeguards and the Additional Protocol in force in the country, suitable geological conditions (including potentially for eventual spent fuel storage), a stable government and system of government, and the approval of that country's people.

Appendix III. The Fuel Process and Risk Management[42]

The amount of time to construct a nuclear power plant, once a site has been licensed, could be as short as three years. Most reactors today use low-enriched uranium, with even some heavy water reactors switching from natural uranium to slightly enriched uranium to increase performance. Obtaining the uranium from an existing mine takes almost as long as plant construction, because uranium has to be mined, milled, converted, enriched, and then fabricated into a fuel element. Portions of the fuel elements in the reactor are regularly changed out on an annual, eighteen-month, or longer cycle, depending on the plant. Fabricated fuel is not fully interchangeable.[43]

If a country has few reactors, it may contract with a full nuclear fuel service company like Areva to provide for the reactors' fuel elements. However, for those countries/utilities managing many nuclear reactors, as many utilities do in the United States, the utility operator typically purchases uranium and arranges separate contracts for the services to make the uranium into fuel elements for the utility operator's reactors

Mined uranium provided about 60 percent of the fuel for nuclear power, with the rest coming from the downblending of weapons-grade uranium and the utilization of natural uranium inventories held by utilities, traders, and producers, as well as the re-enrichment of assays and depleted uranium. With anticipated new reactor construction and the expected end of the availability of weapons uranium, countries have become concerned about the availability of uranium supplies. In a wave of mercantilism, some are buying or investing in mines overseas and/or entering long-term contracts for uranium ore purchases. That few uranium converters, enrichers, and fabricators exist adds to utilities' unease.

Although historically the market has been able to supply fuel needs, small market entrants may fear being squeezed out of uranium stock for commercial as well as political reasons in the future.

Power plant operators vary in their fuel supply management techniques. For U.S. utilities, fuel is often fabricated on a just-in-time basis. However, some plants in Asia take a very conservative approach and maintain deep inventories, including of fabricated fuel sufficient for one fuel cycle service or more. Most utility operators may not be sufficiently capitalized to support the carrying costs of such redundant fuel stocks and

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42. The authors would like to thank the Ux Consulting Company, particularly its president, Jeff Combs, and New York Nuclear Corporation, particularly its president Joe McCourt, for their time in providing facts and insights used in this and the following appendix. Any errors or omissions are, however, the responsibility of the authors.

43. According to the discussions at the Special Event conference, for the Western-produced light water reactors, some competitive bidding is possible covering 25 percent of fabricated fuel needs. For Russian-made reactors, only 5 percent of the reactors use non-Russian-produced fuel.

final supplies;[44] may have different risk assessments because of insufficient information, incorrect information, or actually differing risks; may have different risk tolerances; or may be under high pressure for short-term profits and not manage risk well in the long term. These are the very conditions that favor risk management tools such as insurance and contract options.

44. Utilities may choose to store some Uranium Hexafluoride, UF6, outside of the supply pipeline leading to fabrication, as the final fabricated fuel product can vary based on the utility's fuel requirement and on technological innovations.

Appendix IV. The Commoditization of Enriched Uranium

When a fuel is a commodity—for example, light crude oil—users may worry about fluctuations in prices but will worry less about overall availability of supplies. Is such an evolution possible for enriched uranium?

For a good to be a commodity, it has to be available as a standard product and traded in sufficient quantity among a number of participants to make a market. Today, however, there is no widely accepted formal market for trading enriched uranium as there is for other commodities such as oil. Uranium price and volume indicators are developed by a small number of private organizations that independently monitor uranium market activities, including offers, bids, and transactions. We believe nuclear fuel has the potential to be commoditized, especially given recent trends in trading.

Spot and Term Market for Natural Uranium

The spot market (quick sell, one to a few weeks) in natural uranium in 2005 as recorded by Ux Consulting was estimated at about $1 billion, but the market is somewhat opaque because not all transactions are recorded. Investors/hedge funds entered the market strongly that year and accounted for 25 percent of the transactions by volume (tons)—although only 107 transactions were recorded. In 2006, the investors/funds were accounting for about 35 percent of the spot market. For many years, spot uranium prices remained quite low, trading below $40/pound. The spot price, however, has increased considerably in the past 6 months. For example, the weekly spot for the price of U_3O_8 was $45 per pound in July 2006 and $75 in February 2007 (which could make some mining projects that were seen before as uneconomic now look attractive).[45]

The (long) term market (several years) had fewer contracts—only 64 in 2005—but the contracts were larger making the volume seven times the spot market. In the last several years, the term market volume has more than tripled as buyers seek to lock in uranium supplies, although the delivery price is not locked in (with contracts containing price floors and some ceilings). These contracts called for deliveries to start an average of 2.7 years after contract signing and run for an average of 6.2 years, according to Ux Consulting, which tracks market activity.

Enriched Uranium

In the past, there has been some trading in enriched uranium. Today's tight markets, however, mean the secondary market in enrichment and enriched uranium product is not active. Some contract swapping in enriched uranium does also take place, but this is

45. See Ann Davis, "New Exotic Focus For Hedge Funds: Uranium Market," *Wall Street Journal*, March 5, 2007, p. A1.

driven by the need to satisfy contract conditions imposed by countries (e.g., U.S. flag material can only go certain places) and by certain treaty conventions on third party liabilities. Establishing a larger market in cylinders of enriched UF_6 is therefore not beyond the realm of reason.

A fuller market in natural uranium has not developed until now probably for several reasons. In a small market, contract terms are closely held. Today's suppliers have little interest in commoditizing their product because the contract terms they have negotiated typically include floors but limited ceilings over a guaranteed contract volume. The future prices are set based on some market-related prices related to some (not formalized) market reporting. Suppliers might want a market to develop if they wanted, first, to be assured of more transparent market mechanisms for determining prices; second, to be able to hedge their contracts in a futures market; and third, to be able to raise additional income by selling options beyond existing commitments consistent with practices allowed by a market maker.

Today's purchasers are locking in uranium volumes with some open pricing, given both that purchasers fear for availability and that fuel costs are a relatively small part of the average cost of the kilowatt hour produced (compared to other types of electricity-generating plants). The establishment of a market mechanism for trading would allow clear price hedging and expanded options as speculators/investors added to volume.

Fears about long term commercial supply needs and evident third party investor interest could lead to better market development—if there were an appropriate market maker. As governments have an interest in market stability, their ability to affect the market via "dumping" highly enriched uranium should not be a discouragement. Currently, some brokers and traders provide limited market smoothings. New York Nuclear Corporation (NYNCO) is attempting to establish interest in electronic trading among registered counterparties.

The natural uranium market may be small by other market standards but is estimated to be worth an estimated minimum of $5 billion per year if all transactions were recorded. Market turnover and investor interest could certainly lead to natural uranium trading 10 times greater—to $50 billion per year. Contracts could be easily standardized, as they already include a limited number of delivery points, ASTM specifications, and timing elements. NYNCO offers blind trading in U_3O_8, UF_6, and SWUs in specific lot sizes with two delivery dates per year. However, purchasers typically are responsible for more than just uranium purchases and have been slow to use the online trading platform.

The enriched uranium market could also be traded with standard contracts covering cylinders of enriched UF_6. IAEA or an IAEA-affiliated entity could set up an affiliated arm to educate the buyers, be the active market maker in this product, and control contract deliveries. It could maintain a fuel bank with contracts it purchased online from multiple suppliers but need not take actual delivery to a warehouse—it could continually trade out to the future.

The dominance in the market of government-affiliated players would have to be managed, with agreements covering dumping, introduction of HEU supplies, and other issues. USEC and Areva, which operate more costly gas diffusion enrichment facilities, could find they need to convert to cheaper centrifuge enrichment faster. Alternatively they might find enriched uranium prices make it worth their maintaining the diffusion facilities to supplement their capacity in the short term, even beyond what they might plan today to maintain.

The benefits of having enriched uranium become a commodity are as follows:

- Supply becomes more fungible, so purchasers need not be locked into one supplier. The diversity of suppliers and their actual presence in the market add to a utility's security and allow for better risk management while futures markets and options trading also develop.

- A well-organized market facilitates trade without respect to identity (although physical deliveries could go only to safeguarded, IAEA-approved sites). Standardized contracts could also facilitate title trading, all of which would help obviate political risk.

- More funds would be drawn to the market from investors/speculators, and this increased demand would drive up prices—causing supplies to also increase. As a result, commodity product prices should tend to move lower over time.

- More efficient producers would dominate, discouraging new market entrants, which would reduce proliferation.

It is interesting to note that Uranium Participation Corporation raised C$100 million in 2006 for uranium investments and is traded on the Toronto Exchange. Could IAEA set up a nonprofit Exchange-traded fund?

For this to work in the most ideal way:

- All parts of the fuel fabrication process should have more than one supplier.

- New nuclear facilities should have multiple licensed fabricated fuel providers.

- All participating states would have to agree not to take recriminatory actions against other states for obeying certain preagreed IAEA-facilitated supply arrangements to reduce the risk of suppliers taking concerted action.

- The participating states would have to agree to allow for flag-swapping of goods in transit per the request of IAEA-affiliate and fuel owner providers (who had sold the options).

- The participating states would have to have preapproved exports to the IAEA-affiliated mutual (per the United Kingdom's concept).

The possible effects on the sanctioner must be more painful than the impact of the sanctions is on the sanctioned state, as perceived by the sanctioner.

Thus, if "Country X" thought the IAEA could convince some states to redirect some fuel supplies to a state that Country X wanted to sanction, and if Country X risked losing some fuel security itself, then it would not instigate any nuclear-related embargoes in the first place. This could lead to an overall more stable system—in nuclear terms.

Appendix V. Requirements for Participation in the Mutual Insurance: Understanding the Tradeoffs

Discussions with the countries/utilities involved in nuclear fuel facilities will lead to structuring participation requirements for the mutual so that the demand for the product is highest given the proliferation constraints. The standards for participation should be set low enough so that some agreement can be reached.

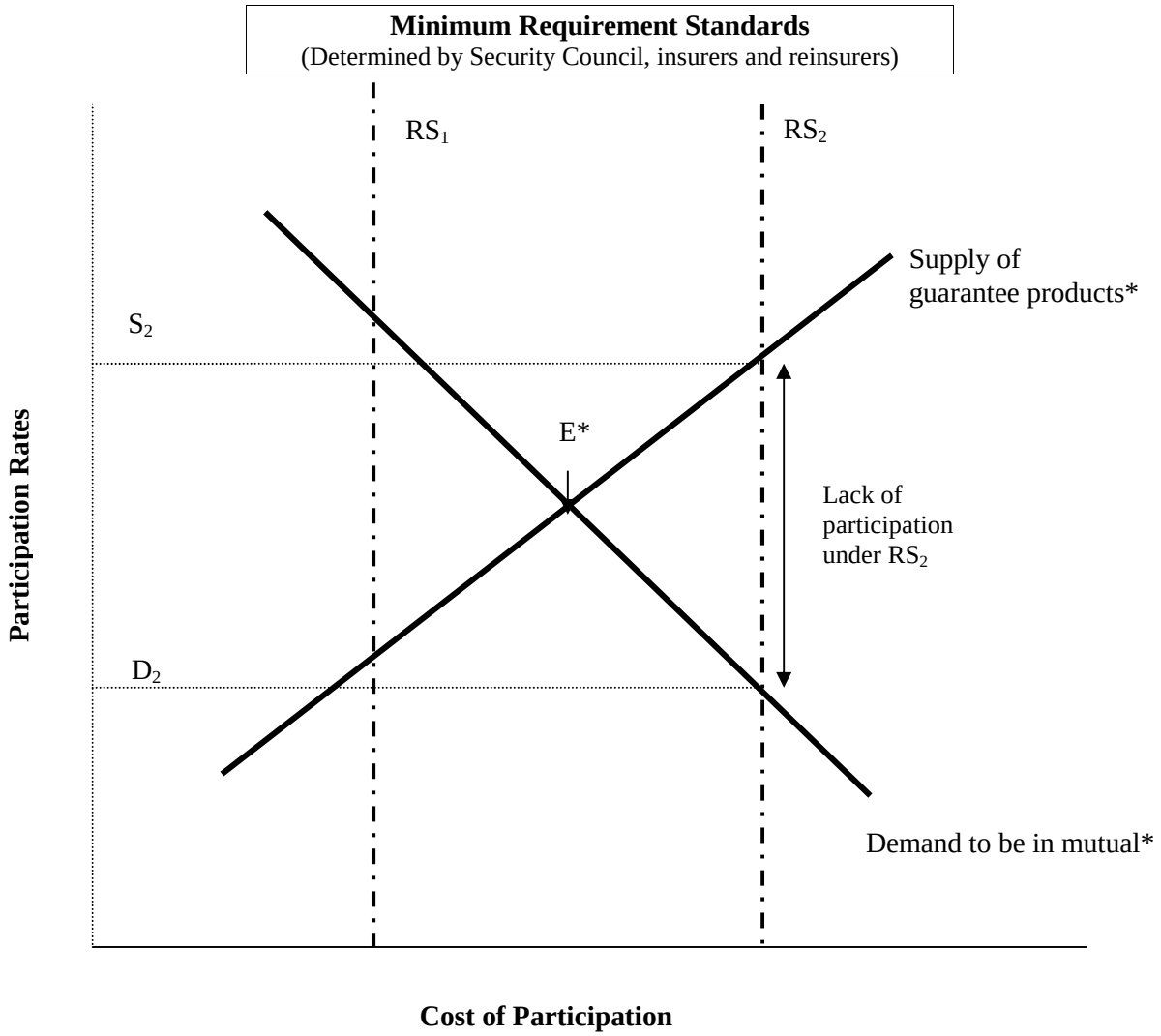
Countries that are worried about fuel supply will want the product if the requirements for participation are low—that is, for example, if the costs are low, both in terms of money and restrictions. At the extreme, if countries are not restricted from enriching nuclear fuel themselves, not required to enforce safeguard agreements, and/or are not forced to comply with all the UN directives on securing facilities, then the demand for the product will be higher. The lower the requirements for participation in financial and behavioral terms, the higher the demand for the product is likely to be.

Such wide latitude for participation may provide fuel assurance but would miss the point of the assurance in terms of discouraging nonproliferation. Some countries that have already met these requirements (i.e., those that already enrich fuel, have safeguards in place, and so on) and that will promote the concept of fuel assurance will want to keep the restrictions as high as possible to encourage nonproliferation. They might see an interest in participating in a mutual facility where the restrictions are high as they value nonproliferation more than other countries.

What is high enough or low enough begs further discussion. The graph below illustrates this trade-off in a very simplified way with the financial and restrictive costs of participations combined.

- (RS_1) line reflects a state where Requirement Standards on participation are low enough to allow some agreement to be reached. Demand for the product and supply can intersect at the equilibrium E*.

- (RS_2) line reflects a state where the Requirement standards for participation are set too high in regard to demand. The participation rate is D_2, even though suppliers would be willing to serve a much higher number of participants, S_2. For example, if a requirement were that new enrichment by participating states would not be allowed, demand for participation might be low.



* Desirability in terms of limiting proliferation (aggregate of countries/utilities)

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