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PAPERS

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# Stop the Fuel Cycle, I Want to Get Off

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We cannot solve proliferation problems one country at a time. Nor can military means or export controls play the lead roles in our efforts. Proliferation is essentially a political problem requiring a political solution. A comprehensive solution must include the reform of the ownership and control of the means of producing fuel for nuclear reactors. Proposals for doing so have been advanced by President George Bush, International Atomic Energy Agency (IAEA) Director-General Mohamed ElBaradei, and by leading non-governmental experts, including several from the Carnegie Endowment for International Peace in the recent report, *Universal Compliance: A Strategy for Nuclear Security*.

All of these proposals seek to end the further production of materials for use in nuclear weapons (highly enriched uranium and plutonium) and stop—at least temporarily—the construction of new facilities for enriching uranium or separating plutonium. Some propose that all such enrichment or separation take place only in facilities owned and operated by multinational entities, others seek tougher export controls to prevent the develop-

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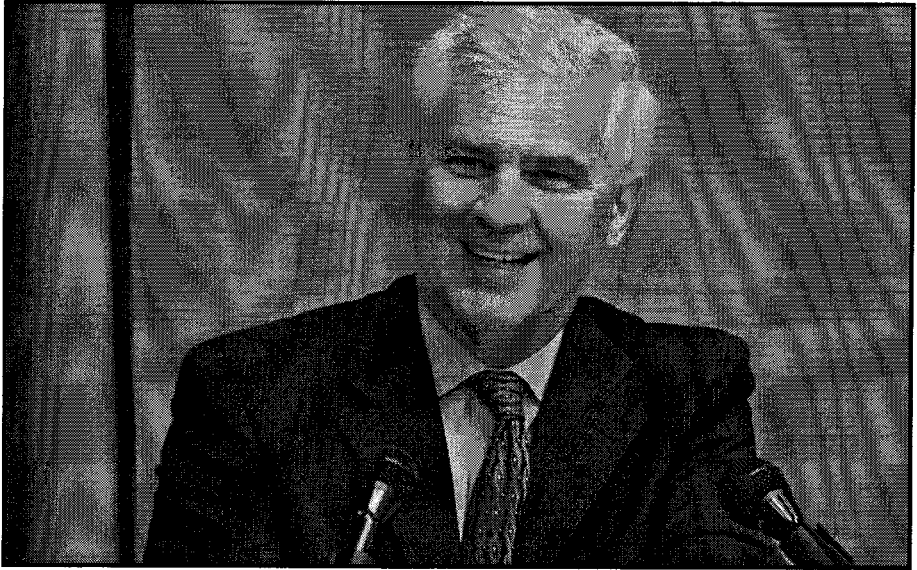
ment of new nuclear fuel factories, while others propose new contractual and commercial means of control. In spite of these differences, all recognize that preventing nations such as Iran or Brazil from entering the uranium enrichment business will require more than a country-specific approach.

### THE CASE OF IRAN

Think for a moment about what it will take to convince the current or future Iranian government to abandon its plans to build between six and twenty nuclear power reactors and all the facilities needed to make and reprocess the fuel for those reactors. Such plans predate the Islamic Republic. The United States, in fact, provided Iran with its first research reactor in the late 1960s, which is still in operation at the University of Teheran, and encouraged Iran in its nuclear pursuits. In the 1970s, this encouragement included agreement by senior officials, such as Henry Kissinger, Donald Rumsfeld, Paul Wolfowitz, and Richard Cheney, that Iran could develop indigenous facilities for enriching uranium and for reprocessing the spent fuel from nuclear reactors. Then-ruler Shah Reza Pahlevi developed plans to build 22 nuclear power reactors with an electrical output of 23,000 megawatts.

Today, the Iranian government and public are again convinced that Iran needs to develop nuclear power and the same indigenous fuel cycle capabilities as it planned under the Shah. Given the clandestine nature of this program (until its exposure in late 2002), the United States, the European Union, and other countries are understandably suspicious that the program is a cover for obtaining the technologies needed to make nuclear weapons. In particular, as John Deutch, Arnold Kanter, and their co-authors pointed out in a 2005 *Survival* article, "For countries with relatively small nuclear energy programs (less than 25,000 megawatts or so), economics will almost always make indigenous enrichment and reprocessing facilities a higher cost option compared to purchasing fuel service on the international market)."<sup>1</sup> Iran, however, insists that it must forge ahead with enrichment plants even though it has yet to put its first 1,000 megawatt reactor into operation.

Whatever its true intentions, convincing Iran that while it could proceed with construction of power reactors, the country must abandon construction of fuel manufacturing facilities will not be easy. It will likely require more than threats of sanctions or military action, more than promises of the economic benefits of cooperation, and perhaps even more than assurances that agreements on nuclear programs would end efforts by the United States and Israel to remove the current regime.



This is the package of carrots and sticks that have comprised the current negotiations between the European Union and Iran. Calibrating the right balance in this mix is difficult enough, but the package itself is probably not sufficient to seal a deal. The new, hard-line government of President Mahmoud Ahmadinejad has further complicated the issue with its harsh rhetorical insistence on proceeding with the nuclear plans and pointed threats to Israel. While the rhetoric may eventually fade, at the core, Iran or any country's reasons for wanting its own fuel cycle capabilities are similar to the reasons some countries want nuclear weapons: security, prestige, and domestic political pressures. All of these must be addressed in order to craft a permanent solution.

Part of Iran's security dilemma can be addressed by the prospect of a new relationship with the United States that ends regime change efforts, but there is also a regional dimension. Ending the threat from an Iranian nuclear program will require placing the Iranian decision in the context of the long-standing U.S. goal of a Middle East free of nuclear weapons. It will be impossible for a country as important as Iran to abstain permanently from acquiring the technologies for producing nuclear weapons—at least as a hedge—if other countries in the region have them. Iran's leaders will want some assurance that there is a process underway that can remove what they see as potential threats from their neighbors, including Israel. For domestic political reasons, they will want to present their nuclear abstinence as part of a movement toward a shared and balanced regional commitment.

Other nations also recognize the need for a balanced, comprehensive

approach. That is why the majority of the members of the IAEA Board of Governors insisted on including a clause to this effect in the February 6, 2005, resolution reporting Iran to the UN Security Council. The resolution, after amendment, noted that Iran's suspension of its uranium enrichment activities would be a step towards the development of a Middle East free of nuclear weapons. Such language is likely to be included in all Security Council resolutions as well.

But the creation of a nuclear-weapons-free zone in the Middle East is still not the hard part. Similar zones have been created in other regions that, though not as intensely contested as the Middle East, still had to overcome substantial rivalries and involved the abandonment of existing programs (in South America) and the dismantlement of actual weapons (in Africa and Central Asia). Little diplomatic effort has been put behind the declared U.S. policy in recent years—certainly nothing on the scale of the effort Republicans and Democrats put toward the creation of the nuclear Non-Proliferation Treaty and its support mechanisms in the 1960s and 1970s. Ridding the region of nuclear weapons will, of course, be difficult, but it is far better than the alternative of a Middle East with not one nuclear power (Israel) but two, three, or four nuclear weapon states as well as unresolved territorial, religious, and political disputes. The latter is a recipe for nuclear war.

The real heavy lifting required for a permanent solution to Iran's nuclear ambitions will come in developing an effort to fundamentally change the way nuclear fuel is produced and reprocessed. If done correctly, it would satisfy a nation's energy security considerations, while saving it the expense of building its own production and reprocessing facilities in order to have a secure supply of fuel for its reactors. Some Iranians see the current negotiations as a new effort by the West to place them, once again, in a dependent relationship. This time the West would not control their oil, they say, but the energy of the future, nuclear fuel. Iran, indeed any nation, will not permanently acquiesce to a discriminatory regime that adds to the existing inequality, which permits some countries to have nuclear weapons while others cannot, by a new inequality that would allow some countries to make nuclear fuel while others could not.

Reforming the current system, however, will require overcoming billions of dollars worth of corporate and national investments and core national commitments to the present methods of producing and disposing of nuclear fuel. Thorough reform, however, is the only sure way to prevent more and more nations from acquiring the technology that can bring them—legally—right up to the threshold of a nuclear weapons capability.

## THE TROUBLE WITH FUEL

The core proliferation problem is not with nuclear reactors. The problem is what goes into and comes out of the reactors. The same facilities that enrich uranium to low levels for fuel can be used to enrich uranium to high levels for bombs. The same facilities that reprocess spent reactor fuel rods for disposal can be used to extract plutonium for weapons.

Over 30 countries have nuclear power reactors, and very few of them make their own fuel. Most purchase it from one of the six countries that make the fuel or from the one existing international consortium, the Uranium Enrichment Corporation (URENCO). China, France, Japan, Pakistan, Russia, and United States are the only countries that currently enrich uranium in significant quantities. Germany, the Netherlands, and the United Kingdom together produce fuel in facilities owned jointly by URENCO. In addition to Iran, Brazil plans to open an enrichment facility in 2006 and other countries, such as South Korea and Ukraine, have indicated interest in developing their own facilities. North Korea may also have a secret uranium enrichment facility, but—if this is the case—this would clearly be for weapons purposes.

From the very beginning of the nuclear age, scientists and policy-makers have tried to control the production of fuel. Even before the first atomic bomb was tested in 1945, scientists working on the production of material for the bomb issued a joint report under the leadership of Nobel Laureate James Franck warning of the dangers of unregulated nuclear technology. The Franck Report pinpointed nuclear materials as the critical choke point. The scientists believed that the rationing of uranium ores could be the simplest way to control nuclear technology. Under an international agreement, uranium would be accounted for, and there would be a check on the conversion of natural uranium into fissile material, verified by strict controls.

The impulse found new life after the war in the plan Bernard Baruch presented to the United Nations for the Truman administration. The Baruch plan built on the Acheson-Lilienthal report, submitted to President Truman by then-Undersecretary of State Dean Acheson and U.S. Atomic Energy Commission chairman David Lilienthal in March 1946. The plan sought to establish an International Atomic Development Authority that would own and control all “dangerous” elements of the nuclear fuel cycle, including all uranium mining, processing, conversion, and enrichment facilities. Only “non-dangerous” activities could be con-

ducted on a national level and, even then, only with a license granted by the proposed Authority. Cold War tensions soon killed this effort.

President Dwight D. Eisenhower picked up parts of these ideas in his Atoms for Peace Program in 1953, proposing the creation of an International Atomic Energy Agency. The United Nations agreed to create the IAEA in 1956, giving the agency controls over excess special fissionable materials. In the decades that followed, there were several major efforts that either studied or recommended the creation of multinational fuel supply centers. These included the International Nuclear Fuel Cycle Evaluation, the United Nations Conference for the Promotion of International Cooperation in the Peaceful Uses of Nuclear Energy, and the Committee on the Assurances of Supply. None succeeded in establishing a independent fuel production mechanism.

### CURRENT PROPOSALS

President Bush, IAEA Director-General ElBaradei, a special high-level panel reporting to the UN secretary-general, an expert panel commissioned by ElBaradei, and others have endorsed radical fuel cycle reform. On February 11, 2004, President Bush said:

The world must create a safe, orderly system to field civilian nuclear plants without adding to the danger of weapons proliferation. The world's leading nuclear exporters should ensure that states have reliable access at reasonable cost to fuel for civilian reactors, so long as those states renounce enrichment and reprocessing. Enrichment and reprocessing are not necessary for nations seeking to harness nuclear energy for peaceful purposes.<sup>2</sup>

ElBaradei agrees. "The wide dissemination of the most proliferation-sensitive parts of the nuclear fuel cycle . . . could be the 'Achilles' heel' of the nuclear non-proliferation regime," he warned in March 2004. "It is important to tighten control over these operations, which could be done by bringing them under some form of multilateral control, in a limited number of regional centers."

ElBaradei proposes a three-part solution:

First, it is time to limit the processing of weapon-usable material (separated plutonium and high-enriched uranium) in civilian nuclear programmes, as well as the production of new material through reprocessing and enrichment, by agreeing to restrict these operations exclusively to facilities under multinational control.

Second, nuclear-energy systems should be deployed that, by design, avoid the use of materials that may be applied directly to making nuclear weapons. These systems should have built-in features that would prevent countries diverting material to weapons production. . . . In addition, existing facilities around the world that use highly-enriched uranium applications—for example, to produce medical radioisotopes—should continue, gradually but irreversibly, to be converted to low-enriched processes.

Third, we should consider multinational approaches to the management and disposal of spent fuel and radioactive waste. More than 50 countries have spent fuel stored in temporary sites, awaiting reprocessing or disposal. Not all countries have the right geology to store waste underground and, for many countries with small nuclear programmes for electricity generation or for research, the costs of such a facility are prohibitive.<sup>3</sup>

The Expert Panel on the nuclear fuel cycle reported back to the IAEA director-general in 2005. The report identified possible multilateral approaches to fuel cycle reform and attempted to analyze the benefits and difficulties of each arrangement. Despite identifying a number of options deserving further consideration, the report stressed that the recommendations were merely a building block and not a final proposal.<sup>4</sup>

Meanwhile, little progress has been made in furthering President Bush's proposed reforms, in part due to a lack of U.S. follow-up and in part to wide resistance to the needed changes. There are concerns among developing nations that a supplier cartel would unduly restrict their access to nuclear technology and a broader reluctance among non-nuclear weapon states to accept more stringent nonproliferation obligations when nuclear weapon states are seen as failing in their commitments to disarmament.

For example, while the Bush proposal recognized the risks associated with the expansion of nuclear production capabilities into new states, his statement failed to take account of the dangers posed by the continued production of weapon-usable materials in states where they already exist. This seemed to perpetuate an unfair two-tier system. In addition to the existing divide of states that have nuclear weapons and states that do not, the proposal seemed to add a new distinction between states allowed to have fuel facilities and states that are not. Iranian officials have seized on this apparent discrimination with some success. They insist that they—and all states—have a right to this technology.

## INDEFINITE ARTICLES

This claim is based on Article IV of the Non-Proliferation Treaty that states:

1. Nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production, and use of nuclear energy for peaceful purposes without discrimination and in conformity with articles I and II of this Treaty.
2. All the Parties to the Treaty undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials, and scientific and technological information for the peaceful uses of nuclear energy. Parties to the Treaty in a position to do so shall also cooperate in contributing alone or together with other States or international organizations to the further development of the applications of nuclear energy for peaceful purposes, especially in the territories of non-nuclear-weapon States Party to the Treaty, with due consideration for the needs of the developing areas of the world.

There is a growing debate, however, whether the existence of facilities capable of producing weapon-usable materials can be considered consistent with this “peaceful uses” clause or with the obligation of non-nuclear weapon states under Article II of the Treaty not to pursue nuclear weapons.

In its 2004 report, the UN High-Level Panel to the secretary-general recognized the problem, but straddled the issue by stating that “the mounting tension between the goals of achieving a more effective nonproliferation regime and the right of all signatories of the [NPT] to develop civilian nuclear industries needs to be addressed.” This avoidance reflects the panel’s recognition that reinterpreting the NPT to restrict the ability of states to develop or possess such facilities and materials will be exceedingly difficult. States seeking this new definition, especially nuclear weapon states, will be confronted by an openly skeptical group of states unwilling to cede any ground on their access to nuclear technology as long as other existing nonproliferation obligations, including those associated with disarmament, are perceived as going unimplemented. To obtain a legal endorsement of some new standard, advocating states will need—and should be willing—to give more in order to get more.

The Carnegie report *Universal Compliance* recommends that the first step should be a new international fuel cycle arrangement that would guarantee fuel cycle services to states that do not possess domestic fuel



cycle capabilities. Such a mechanism would have to provide a credible international guarantee of fresh reactor fuel and removal of spent fuel at prices that offer an economic incentive to the recipient state. Such an arrangement would reduce, if not eliminate, the economic or energy security justification for states to pursue their own fuel cycle facilities and, in so doing, would test states' commitment to a nonweapons path. States that turn down reliable and economically attractive alternatives to costly new production facilities would engender suspicion of their intentions, inviting sanctions and other international pressures.

To date, several potential mechanisms for guaranteeing the supply of fresh fuel have been put forward, as described in Table 1. The second and third are very close to proposals advanced by President Dwight D. Eisenhower in his original Atoms for Peace plan, but are now enjoying something of a renaissance. Successful options will need to assure recipients that the supply arrangements will be inviolable, and the most effective will include redundant systems to provide fuel should primary sources fail.

*Table 1*

**OPTIONS FOR PROVIDING  
GUARANTEED SUPPLIES OF NUCLEAR FUEL<sup>5</sup>**

There are a number of possible arrangements for ensuring that states that abandon fuel cycle capabilities can obtain guaranteed access to fuel services. The goal in each case would be to undercut the economic argument for programs to develop indigenous enrichment capabilities.

**A COMMERCIAL CONSORTIUM OF FUEL PROVIDERS:**

Government-backed collections of fuel-producing states or companies could form supply groups to commercially outcompete domestic fuel production programs. Three or more fuel-providing entities could offer reinforcing contracts to prospective buyers (if one company dropped out, another would be obligated to fulfill the contract). The fuel could be sold or leased (depending on recipient states' ability to manage spent fuel). Such an initiative would require a new level of cooperation and coordination between companies that have fiercely guarded their commercial relationships and would require intense government-corporate interactions. All of the affected companies, however, already have close (if not coordinate) relationships with their national governments, which could be used to ensure cooperation with the proposed new arrangements.

**INTERNATIONALLY MANAGED STOCKS OF FUEL:** The IAEA statute allows for states to donate nuclear materials to the control of the agency, which it can then use as directed by the IAEA Board of Governors. States could transfer the “flag” or ownership of fresh nuclear fuel that could then be transferred by the agency to the states on an economically viable basis. Transfers could be made to the IAEA in lieu of or in addition to voluntary contributions to the IAEA, or seed money could be used to start a cost-neutral program of fuel transfers by the agency. In addition, the IAEA could take possession of stocks in smaller amounts to serve as a backup to commercial contracts. In the event that political, economic, or technical factors led to the end of a fuel supply arrangement, the IAEA could step in, backstopping and thereby guaranteeing continuous supply.

**BLIND AUCTIONS OF FUEL:** Fuel supply guarantees could be provided not to states but to the IAEA, which could then be empowered to conduct auctions among eligible states for the material. This would mean that states or companies would not be in a direct position to deny fuel services, since the fuel would be provided directly to and by the IAEA or some alternate body. Companies might commit (or be persuaded to commit) to provide the IAEA with a certain amount of fuel per year. Providing states would then have to fulfill these commitments, increasing the resilience of the guarantees. A political commitment could also be created under which all such sales are required to go through the IAEA as a form of control and transparency.

**IAEA AS GUARANTOR:** The IAEA could itself provide fuel guarantees to states that abstain from acquiring fuel cycle capabilities. In turn, supplying companies or states (or both) would then be required to fulfill IAEA obligations for fuel supply. Leading supplying states could sign agreements with the IAEA to fulfill commitments made by the agency on their behalf.

John Deutch, Arnold Kanter, Ernest Moniz, and Daniel Poneman proposed perhaps the most developed commercial idea in their 2005 *Survival* article. They call for an “Assured Nuclear Fuel Services Initiative.” Here is how it would work:

Countries that do not currently possess uranium enrichment or plutonium reprocessing facilities would agree not to obtain any such

facilities or related technologies and materials for an extended period of time. By the same logic, countries that do possess such facilities would agree not to provide them, or related equipment or technology, to countries that do not. In exchange, during this period they would receive, on attractive terms, guaranteed cradle-to-grave fuel services—specifically, fresh nuclear fuel supply and spent fuel removal—under an agreement signed by all those governments in a position to provide such services. The IAEA would apply safeguards to any fuel cycle activities covered by the agreement in addition to its traditional safeguard duties on the reactors in the user states. Fuel service transactions themselves, however, would be between commercial entities negotiating commercial contracts.<sup>6</sup>

The authors believe their proposal could work because it is based on economic incentives, not strictly political ones. They appeal to the nuclear power industry to realize that failure to reform the fuel cycle will lead inevitably to a country making the leap from civilian nuclear power to military nuclear weapons—with devastating consequences for the industry.

The Assured Nuclear Fuel Services Initiative offers something for everyone. Nuclear supplier states would obtain revenues and increased confidence in avoiding a proliferation incident in a third country whose actions could put the large and potentially growing fleet of nuclear power stations in operation around the world at risk (a “proliferation Chernobyl”). User states would obtain cost-effective, guaranteed access to nuclear fuel and guaranteed relief from the burden of dealing with nuclear waste management. And the world would gain an added measure of safety from the risk of weapons proliferation that the spread of inherently dangerous fuel cycle facilities would bring.<sup>7</sup>

## **TIME FOR LEADERSHIP**

The Iran crisis could be the crucible that forges the international agreement necessary to finally reform the fuel cycle. It need not be a global solution: a regional or Iran-specific approach would be more feasible and, if successful, serve as a model for a more generalized reform. Similarly, the proliferation damage done by President Bush’s agreement to sell nuclear fuel and reactors to India, despite NPT restrictions against such sales, might be ameliorated in part by having such sales take place within an international consortium or contractual agreement. The United States should be the natural leader of these efforts. It will require a departure from the administration’s counterproliferation strategy that remains fixed on regime change.

It is time to recognize the failure of this approach. Attempting to stem nuclear proliferation crisis by crisis—from Iraq, to North Korea, to Iran, and so on—ultimately invites defeat. As each deal is cut, it sets a new expectation for the next proliferator. Regime change by force in country after country is neither right nor realistic. The United States would bankrupt and isolate itself, all the while convincing additional countries that nuclear weapons would be their only protection.

A more systematic approach that prevents states within the NPT from acquiring the nuclear infrastructure needed to produce nuclear weapons is the only real sustainable option. Reforming the fuel cycle thus must join the urgent task of securing weapon-usable fissile materials as our two greatest nonproliferation priorities. As President George W. Bush has said, “The nations of the world must do all we can to secure and eliminate nuclear . . . materials.”

Few would argue that today we are doing “all we can.” The current piecemeal efforts will not adequately protect fissile materials from theft or prevent the spread of new uranium and plutonium plants. While economic and political compromises will have to be made, a new, expanded and tightened regime can be compatible with full use of nuclear energy and should be undertaken in cooperation with the nuclear industry. It is important to recognize that the viability of the nuclear industry is at stake: The violent use of stolen fissile material or the collapse of the nonproliferation regime would set back the use of nuclear power generation worldwide.

We have no time to waste. As Mohamed ElBaradei points out, “We have not yet reached the mid-1960s’ prediction of a world of 15 or more nuclear-weapon states, but we are over halfway there. And the trends indicated by recent events should have us all worried.”<sup>8</sup>

**URANIUM ENRICHMENT FACILITIES<sup>9</sup>**

<i>Country</i>	<i>Type</i>	<i>Capacity (1000 SWU)<sup>10</sup></i>
China	Gaseous Diffusion	900
China	Centrifuge	1000 (total)
France	Gaseous Diffusion	10,800
Germany	Centrifuge	1,462.5
Japan	Centrifuge	1,250 (total)
The Netherlands	Centrifuge	1,950
Pakistan	Centrifuge	5
Russia	Centrifuge	15,000 (total)
United Kingdom	Centrifuge	2,437.5
United States	Gaseous Diffusion	18,700 (total)

**URANIUM HEXAFLUORIDE CONVERSION FACILITIES<sup>11</sup>**

<i>Country</i>	<i>Capacity (MTU/year)<sup>12</sup></i>
Brazil	90
Canada	10,500
China	400
France	14,350 (total)
Iran	193
Russia	24,000
United Kingdom	6,000
United States	14,000

**MIXED OXIDE (MOX) FUEL FABRICATION<sup>13</sup>**

<i>Country</i>	<i>Capacity (MTIHM/year)<sup>14</sup></i>
Belgium	37
France	235
India	50
Japan	10
United Kingdom	128

NEW FUEL CYCLE FACILITY PROJECTS<sup>15</sup>*North America***CANADA**

SEU Port Hope, Ont.

**UNITED STATES**

USEC Ports, centrifuge plant, OH

NFS Erwin BLEU, TN

DCS MOX plant, SC

LES Lea County enrich. plant, NM

*Europe***UNITED KINGDOM**

Urenco Capenhurst expansion

**THE NETHERLANDS**

Urenco Almelo expansion

**GERMANY**

Urenco Gronau expansion

**FRANCE**

Eurodif Tricastin centrifuge project

*South America***BRAZIL**

Resende enrichment plant

*Asia***RUSSIA**

Seversk MOX plant

**IRAN**

Natanz enrichment plant

**CHINA**

Lanzhou MOX plant

**JAPAN**

Rokkasho MOX plant

**ENDNOTES**

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2 George W. Bush, "President Announces New Measures to Counter the Threat of WMD" Remarks by the President, National Defense University (February 11, 2004), available at <[www.whitehouse.gov/news/releases/2004/02/20040211-4.html](http://www.whitehouse.gov/news/releases/2004/02/20040211-4.html)>.

3 Mohamed ElBaradei, "Towards a Safer World," *The Economist*, October 16, 2003, <[www.iaea.org/NewsCenter/Statements/2003/ebTE20031016.shtml](http://www.iaea.org/NewsCenter/Statements/2003/ebTE20031016.shtml)> (accessed January 30, 2006).

4 IAEA, "Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report submitted to the Director General of the International Atomic Energy Agency," INFCIRC/640, Feb. 22, 2005.

5 Adapted from George Perkovich, Jessica Mathews, Joseph Cirincione, Rose Gottemoeller, and Jon B. Wolfsthal, *Universal Compliance: A Strategy for Nuclear Security* (Washington: Carnegie Endowment for International Peace, March 2005). Available at: <[www.carnegieendowment.org/strategy](http://www.carnegieendowment.org/strategy)> (accessed January 30, 2006).

6 Deutch, 68.

7 Ibid.

8 ElBaradei.

9 WISE Uranium Project, "World Nuclear Fuel Facilities," <[www.wise-uranium.org/efac.html](http://www.wise-uranium.org/efac.html)> (accessed January 30, 2006).

- 10 Separative Work Unit (SWU): The separative work unit, a unit used in the nuclear power industry to describe the work required to enrich uranium (that is, to increase the fraction of uranium 235, the isotope which undergoes fission to produce energy). About 100-120,000 SWU is required to enrich the annual fuel loading for a typical 1000 MWe light water reactor. See Russ Rowlett, "How Many? A Dictionary of Unit of Measurement," (Chapel Hill: University of North Carolina at Chapel Hill, 2004).
- 11 WISE Uranium Project.
- 12 MTU = metric tons of uranium
- 13 WISE Uranium Project.
- 14 MTIHM = metric tons of initial heavy metal
- 15 WISE Uranium Project.

