

CRS Report for Congress

Managing the Nuclear Fuel Cycle: Policy Implications of Expanding Global Access to Nuclear Power

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Summary

After several decades of decline and disfavor, nuclear power is attracting renewed interest. New permit applications for 30 reactors have been filed in the United States, and another 150 are planned or proposed globally, with about a dozen more already under construction. In the United States, interest appears driven, in part, by provisions in the 2005 Energy Policy Act authorizing streamlined licensing that combine construction and operating permits, and tax credits for production from advanced nuclear power facilities. Moreover, the U.S. Department of Energy proposes to spend billions of dollars to develop the next generation of nuclear power technology.

Expanding global access to nuclear power, nevertheless, has the potential to lead to the spread of sensitive nuclear technology. Despite 30 years of effort to limit access to uranium enrichment, several undeterred states pursued clandestine nuclear programs; the A.Q. Khan black market network's sales to Iran and North Korea representing the most egregious examples. Concern over the spread of enrichment and reprocessing technologies, combined with a growing consensus that the world must seek alternatives to dwindling and polluting fossil fuels, may be giving way to optimism that advanced nuclear technologies may offer proliferation resistance.

Proposals offering countries access to nuclear power and thus the fuel cycle have ranged from a formal commitment by these countries to forswear enrichment and reprocessing technology, to a de facto approach in which a state does not operate fuel cycle facilities but makes no explicit commitment, to no restrictions at all. The most recent proposal under the U.S. Global Nuclear Energy Partnership (GNEP) represents a shift in U.S. policy by not requiring participants to forgo domestic fuel cycle programs. Whether developing states will find existing proposals attractive enough to forgo what they see as their "inalienable" right to develop nuclear technology for peaceful purposes remains to be seen.

Congress will have a considerable role in at least four areas of oversight related to fuel cycle proposals. The first is providing funding and oversight of U.S. domestic programs related to expanding nuclear energy in the United States. The second area is policy direction and/or funding for international measures to assure supply. A third set of policy issues may arise in the context of implementing the international component of GNEP. A fourth area in which Congress plays a key role is in the approval of nuclear cooperation agreements. The 110th Congress has introduced several bills related to nuclear energy in the United States and fuel cycle assurances, including H.R. 885, S. 1977, S. 1700, S. 1138, S. 970, and S. 328 (Section 336). This report will be updated as events warrant.

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Introduction

A renewed interest in nuclear power and expanding its role in meeting world energy demands has also led to increased concerns for limiting the spread of nuclear weapons-relevant technology. After languishing for several decades, the United States appears poised for a new phase of nuclear reactor construction. Two new uranium enrichment plants are already under construction in anticipation of an increased demand for nuclear fuel. Spent nuclear fuel disposal has remained the most critical aspect of the nuclear fuel cycle for the United States, where longstanding nonproliferation policy discouraged commercial nuclear fuel reprocessing.¹ Other countries provide commercial reprocessing services and, with several notable exceptions, have kept their commercial and weapons fuel cycles separate. New proposals to offer commercial nuclear power opportunities to non-fuel cycle nations would guarantee them a supply of nuclear fuel in exchange for commitments to forgo enrichment and reprocessing.

The U.S. Department of Energy considers nuclear power as “the only proven technology that can provide abundant supplies of base-load electricity reliably and without air pollution or emissions of greenhouse gases.”² The National Energy Policy Development Group recommended in 2001 that President Bush “support the expansion of nuclear energy in the United States as a major component of our national energy policy.” About the same time, the U.S. Department of Energy (DOE) created the Generation IV International Forum to collaborate with 10 other states in investigating “innovative nuclear energy system concepts for meeting future energy challenges.” The Bush Administration requested millions of dollars from Congress in 2003 to support several programs related to the development of new nuclear power plants in the United States, including the Advanced Fuel Cycle Initiative, and Generation IV. In passing the Energy Policy Act of 2005, Congress created certain incentives and streamlined license application procedures for new nuclear power plants. In February 2006, the Secretary of Energy announced the Global Nuclear Energy Initiative (GNEP) as part of President Bush’s Advanced Energy Initiative.

¹ CRS Report RS22542, *Nuclear Fuel Reprocessing: U.S. Policy Development*, by Anthony Andrews.

² U.S. Department of Energy, “The Global Nuclear Energy Partnership,” Factsheet 06-GA50506-01 (also available at [<http://www.gnep.energy.gov>]).

Meanwhile, concerns over nuclear proliferation have steadily risen as ostensibly commercial uranium enrichment and reprocessing technologies have been subverted for military purposes. In 2003 and 2004, it became evident that Pakistani nuclear scientist A.Q. Khan sold sensitive technology and equipment related to uranium enrichment — a process that can be used to make fuel for nuclear power and research reactors, or to make fissile material for nuclear weapons — to states such as Libya, Iran, and North Korea. Although Pakistan's leaders maintain they did not acquiesce in or abet Khan's activities, Pakistan remains outside the Nuclear Nonproliferation Treaty (NPT) and the Nuclear Suppliers Group (NSG). Iran has been a direct recipient of Pakistani enrichment technology.³

The International Atomic Energy Agency (IAEA)'s Board of Governors found in 2005 that Iran's breach of its safeguards obligations constituted noncompliance with its safeguards agreement, and referred the case to the UN Security Council in February 2006. Despite repeated calls by the UN Security Council for Iran to halt enrichment and reprocessing-related activities, and imposition of sanctions, Iran continues to develop enrichment capability at Natanz.⁴ Iran insists on its inalienable right to develop the peaceful uses of nuclear energy, pursuant to Article IV of the NPT. Interpretations of this right have varied over time.⁵ The IAEA Director General, Mohamed ElBaradei, has not disputed this inalienable right and by and large, neither have U.S. government officials. However, the case of Iran raises perhaps the most critical question in this decade for strengthening the nuclear nonproliferation regime: how can access to sensitive fuel cycle activities (which could be used to produce fissile material for weapons) be circumscribed without further alienating non-nuclear weapon states in the NPT?

Leaders of the international nuclear nonproliferation regime have suggested ways of reining in the diffusion of such inherently dual-use technology, primarily through the creation of incentives not to enrich uranium or reprocess plutonium. The international community is in the process of evaluating those proposals and may decide upon a mix of approaches.

Most of the proposals are not new, but rather variations of those developed thirty or more years ago.⁶ In the 1970s, efforts to limit or manage the spread of

³ CRS Report RS21592, *Iran's Nuclear Program: Recent Developments*, by Sharon Squassoni.

⁴ "Security Council, in Presidential Statement, Underlines Importance of Iran's Re-Establishing Full, Sustained Suspension of Uranium Enrichment Activities," March 29, 2006, at [<http://www.un.org/News/Press/docs/2006/sc8679.doc.htm>], and UN Security Council Resolution 1737 (2006) [<http://www.un.org/News/Press/docs//2006/sc8928.doc.htm>].

⁵ Most observers point to the obligation in Article IV that such pursuit must be consistent with a state's obligations under Articles II and II of the treaty. Article II refers to a state's obligation to forswear nuclear weapons development and Article III refers to a state's obligation to undertake safeguards "for the exclusive purpose of verification of the fulfillment of its obligations" under the treaty.

⁶ See timeline of fuel cycle proposals, available at [<http://www.iaea.org/NewsCenter/>]

nuclear fuel cycle technologies for nonproliferation reasons foundered for technical and political reasons, but many states were nevertheless deterred from enrichment and reprocessing simply by the high technical and financial costs of developing sensitive nuclear technologies, as well as by a slump in the nuclear market. Several developments may now make efforts to limit access to the nuclear fuel cycle more attractive: a growing concern about the spread of enrichment technology (specifically via A.Q. Khan black market network, as well as Iran's efforts); a growing consensus that the world must seek alternatives to polluting fossil fuels; and optimism about new nuclear technologies that may offer more proliferation-resistant systems. Central to the debate is developing proposals attractive enough to compel states to forego what they see as their inalienable right to develop nuclear technology for peaceful purposes.

At the same time, there is debate on how to improve the IAEA safeguards system and its means of detecting diversion of nuclear material to a weapons program in the face of expanded nuclear power facilities worldwide.

This report is intended to provide Members and congressional staff with the background needed to understand the current debate over proposed strategies to redesign the global nuclear fuel cycle. It begins with a look at the motivating factors underlying the resurgent interest in nuclear power, the nuclear power industry's current state of affairs, and the interdependence with the nuclear fuel cycle. A number of proposals have been offered that are aimed at limiting direct participation in the global nuclear fuel industry by assuring access to nuclear fuel supplies:

Year	Agency	Proposal
2003	IAEA	Would establish internationally owned fuel cycle centers.
2004	United States	Would keep uranium enrichment and plutonium reprocessing in the hands of current technology holders, while providing fuel guarantees to those who abandon the option.
2005	IAEA	Explored a variety of options to address front end and back end problems and their attractiveness to different groups of states, and surveyed past proposals.
2005	Russian Federation	Would establish international fuel cycle centers.
2006	United States	U.S. Global Nuclear Energy Partnership originally proposed that certain recognized fuel cycle countries would ensure reliable supply to the rest of the world in return for commitments to renounce enrichment and reprocessing; also proposed solutions for recycling of spent fuel and storage issues.
2006	U.S., U.K., Russia, France, Germany, and Netherlands	Six Country Concept would establish reliable access to nuclear fuel.

⁶ (...continued)
Focus/FuelCycle/key_events.shtml].

Year	Agency	Proposal
2006	Nuclear Threat Initiative	Promised \$50 million for a international nuclear fuel bank under IAEA supervision provided another \$100 million donated within two years and IAEA organizes implementation.
2007	United States	Revised GNEP would promote an international nuclear fuel supply framework (without explicit renunciation of fuel technology) to reduce proliferation risk and a closed fuel cycle featuring recycling techniques that do not separate plutonium.

Renewed Interest in Nuclear Power Expansion⁷

Commercializing nuclear power has proved far more challenging than first envisioned. World nuclear capacity had reached about 200 gigawatts during the 1980s, but as confidence in nuclear power safety declined after accidents at Three-mile Island and Chernobyl, the rate of adding new capacity fell more than 75% during the following decade.⁸ Today, nuclear power provides about 368 gigawatts — 15% of the world's electricity generation. Though a significant amount, it is far less than that projected 50 years ago. High construction and operating costs, safety problems and accidents, and controversy over nuclear waste disposal slowed the worldwide growth of nuclear power.

With uranium once considered a scarce resource, reprocessing was promised as a means of extending the energy remaining in spent nuclear fuel and fast breeder reactor technology promised to produce more fuel than a reactor consumed. In the 1980s, as the economics of nuclear power became questionable with declining fossil fuel prices and increased uranium supplies, national programs to develop fast breeder reactors came nearly to a standstill. Moreover, the plutonium fuel produced by breeder reactors drew strong opposition over its potential use in nuclear weapons.

In the past few years, however, the original promises of nuclear power have attracted renewed interest around the world. What has changed?

Sharply higher prices for oil and natural gas are a fundamental factor in national energy policymaking. Average world oil prices have risen from below \$10 per barrel at the beginning of 1999 to above \$80 per barrel in the Fall of 2007.⁹ U.S. natural gas prices have followed a similar track, and a near-doubling of international

⁷ This section was prepared by Mark Holt, Specialist in Energy Policy, and Anthony Andrews, Specialist in Energy Policy, in the Resources, Science, and Industry Division, Congressional Research Service.

⁸ International Energy Agency, *World Energy Outlook 2006*, p. 349.

⁹ Energy Information Administration, at [<http://tonto.eia.doe.gov/dnav/pet/hist/wtotworldw.htm>].

shipments of liquefied natural gas since 1998¹⁰ indicates that natural gas prices have also risen around the world. As a result, national governments are searching for alternative energy sources, often including nuclear power. However, only 20% of the world's electricity generation is fueled by natural gas and 7% by oil (the majority of the world's electricity is generated from coal),¹¹ so nuclear power's ability to directly substitute for oil and gas is limited, at least in the near term.

For nuclear power to have a significant impact on oil demand, long-term changes in energy-use patterns would have to take place, particularly in the transportation sector. One possibility is that nuclear power plants could be used to produce hydrogen, which could provide energy for fuel-cell vehicles. The U.S. Department of Energy is developing processes that could produce "industrial scale" quantities of hydrogen in a high-temperature reactor by 2019¹² and is concurrently supporting development of fuel cell vehicles. Another possibility is the commercialization of all-electric or plug-in hybrid vehicles that could be recharged with nuclear-generated electricity. But even if such technologies were to be successfully developed, it would take many years for the new vehicles and, in the case of hydrogen, fuel delivery infrastructure to have a significant energy impact.

Government policies aside, higher oil and gas prices are heightening interest in nuclear power by improving current projections of nuclear power's economic viability. In the United States, natural gas has been the overwhelming fuel of choice for new electrical generation capacity since the early 1990s, but recent high prices have caused planned coal-fired capacity in 2009 to reach nearly twice the level of planned gas-fired capacity.¹³ Increased demand has led to rising U.S. prices for coal, which already generates nearly half of U.S. electricity (and 40% of world electricity¹⁴). Because fuel costs constitute a relatively small percentage of nuclear power costs, higher natural gas and coal prices could make new nuclear power plants economically competitive, despite sharply rising uranium prices.¹⁵

Growing worldwide concern about greenhouse gas emissions, particularly carbon dioxide from fossil fuels, has renewed attention to nuclear power's lack of direct CO₂ emissions. Although few national governments or international organizations have explicitly adopted policies in support of nuclear power to reduce greenhouse gas (GHG) emissions, many GHG policies and proposals may indirectly encourage nuclear power expansion. Legislative proposals such as tradeable permits and carbon taxes could increase the cost of electricity from new fossil-fuel-fired power plants above that of nuclear power plants.

¹⁰ EIA [<http://www.eia.doe.gov/emeu/international/gastrade.html>].

¹¹ World Energy Outlook, *op. cit.*, pp. 139, 141.

¹² DOE, *FY 2008 Congressional Budget*, vol. 3, p. 577.

¹³ EIA [<http://www.eia.doe.gov/cneaf/electricity/epa/epat2p4.html>].

¹⁴ World Energy Outlook, *op. cit.*, p. 140.

¹⁵ CRS Report RL33442, *Nuclear Power: Outlook for New U.S. Reactors*, by Larry Parker and Mark Holt.

Some support for nuclear power as a way to reduce GHG emissions has emerged in academic and think-tank circles. As stated by the Massachusetts Institute of Technology in its major study *The Future of Nuclear Power*: “Our position is that the prospect of global climate change from greenhouse gas emissions and the adverse consequences that flow from these emissions is the principal justification for government support of the nuclear energy option.”¹⁶ But environmental groups generally contend that the nuclear accident, waste, and weapons proliferation risks posed by nuclear power outweigh any GHG benefits. The large construction expenditures required by commercial reactors, they contend, would yield greater GHG reductions if used for energy efficiency and renewable generation. Finally, they note that nuclear power, while not directly emitting greenhouse gases, produces indirect emissions through the nuclear fuel cycle and during plant construction.

Another key factor behind the renewed interest in nuclear power is the improved performance of existing reactors. U.S. commercial reactors generated electricity at an average of 89.8% of their total capacity in 2006, after averaging around 75% in the mid-1990s and around 65% in the mid-1980s. Worldwide performance has seen similar improvement.¹⁷ The improved operation of nuclear power plants has helped drive down the cost of nuclear-generated electricity. Average U.S. reactor operations and maintenance costs (including fuel but excluding capital costs) dropped steadily from a high of about 3.5 cents/kilowatt-hour (kwh) in 1987 to below 2 cents/kwh in 2001 (in 2001 dollars).¹⁸ By 2005, the U.S. average operating cost was 1.7 cents/kwh.¹⁹

Nuclear interest has been further increased in the United States by incentives in the Energy Policy Act of 2005 (P.L. 109-58). The law provides a nuclear energy production tax credit for up to 6,000 megawatts of new nuclear capacity, compensation for regulatory delays for the first six new reactors, and federal loan guarantees for nuclear power and other advanced energy technologies. Under certain baseline assumptions, the tax credit could determine whether new U.S. nuclear plants would be economically viable.²⁰

U.S. electric utilities and other companies during the past two years have announced plans to submit license applications to the Nuclear Regulatory Commission (NRC) for more than 30 new commercial reactors (**Table 1**). NRC has issued “early site permits” — which resolve site-related issues for possible future reactor construction — at locations in Illinois and Mississippi and is nearing completion of a third permit in Virginia. The Tennessee Valley Authority board of directors voted August 2, 2007, to restart construction of its long-delayed Watts Bar

¹⁶ Interdisciplinary MIT Study, *The Future of Nuclear Power*, Massachusetts Institute of Technology, 2003, p. 79.

¹⁷ “World Nuclear Generation Sets Record in 2006,” *Nucleonics Week*, February 15, 2007, p. 1; *Nuclear Engineering International*, November 2005, p. 37.

¹⁸ Uranium Information Centre, *The Economics of Nuclear Power*, Briefing Paper 8, January 2006, p. 3.

¹⁹ *Nucleonics Week*, “U.S. Utility Operating Costs, 2005,” September 14, 2006, p. 7.

²⁰ CRS Report RL33442, *op. cit.*

2 reactor, which had been ordered in 1970. But despite that flurry of activity, no new reactor orders have been placed. No reactors have been ordered in the United States since 1978, and all orders after 1973 were subsequently cancelled.

New reactors are on order elsewhere in the world, and several non-nuclear countries have announced that they are considering the nuclear option. As **Figure 1** shows, the vast majority of reactors currently under construction are in Asia, with only a handful in the rest of the world.

Despite the recent positive developments for nuclear power, much uncertainty still remains about its prospects. Construction costs for new nuclear power plants — which were probably the dominant factor in halting the first round of nuclear expansion — continue to loom as a potential insurmountable obstacle to renewed nuclear power growth. Average U.S. nuclear plant construction costs more than doubled from 1971 to 1978, according to the Office of Technology Assessment, and nearly doubled again by the mid-1980s, not including interest accrued during construction.²¹ Including interest, many U.S. nuclear plants proved to be grossly uneconomic, often with capital costs totaling more than \$3,000 per kilowatt of capacity in 2000 dollars,²² and relying on the utility regulatory system to recover their costs.

Major reactor vendors, such as General Electric and Westinghouse, contend that new designs and construction methods will cut costs considerably. Nuclear supporters also point to a new U.S. nuclear licensing system that is intended to avoid some of the regulatory problems that delayed completion of some reactors in the past. No U.S. commercial reactor has been completed during the past decade, however, and the new licensing system has yet to be tested. The French reactor vendor Areva estimated that the first of its newly designed power plants in France would cost \$2,600 per kilowatt, which would be high in the likely range of economic viability. Reported construction costs of reactors completed around the world since the 1990s range so widely and vary so much in circumstance that they provide little insight into probable future costs.²³

Many other important factors in the future of nuclear power are similarly uncertain. Prices of competing fuels, particularly natural gas, have risen recently but have been volatile in the recent past. If fossil fuel prices become depressed for a sustained period, as in the late 1980s through the 1990s, support for nuclear power as an alternative energy source could again be undermined. Major accidents, such as Three Mile Island and Chernobyl, would almost certainly diminish public support for nuclear power. Disposal of high-level nuclear waste, which reprocessing or recycling is intended to address, will continue to generate controversy as

²¹ Office of Technology Assessment, *Nuclear Power in an Age of Uncertainty*, OTA-E-216, February 1984, p. 59.

²² Jan Willem Storm van Leeuwen and Philip Smith, *Nuclear Energy, the Energy Balance*, July 31, 2005, Chapter 3, p. 2.

²³ Numerous published sources, available from the author.

governments attempt to develop permanent underground repositories — none of which are yet operating.

Table 1. Announced U.S. Nuclear Plant License Applications

Announced Applicant	Site	Planned Application	Reactor Type	Units
Alternate Energy	Bruneau (ID)	2008	Areva EPR	1
Ameren	Callaway (MO)	2008	Areva EPR	1
Amarillo Power	Vicinity of Amarillo (TX)	2008	EPR	2
Constellation Energy (Unistar)	Calvert Cliffs (MD)	Submitted July 2007 (Part 1)	Areva EPR	1
	Nine Mile Point (NY)	1 st half 2008	Areva EPR	1
	Not specified	4Q 2008	Areva EPR	1
Dominion	North Anna (VA)	Nov. 2007	GE ESBWR	1
DTE Energy	Fermi (MI)	4Q 2008	Not specified	1
Duke Energy	Cherokee (SC)	2007-2008	Westinghouse AP1000	2
Entergy	River Bend (LA)	May 2008	GE ESBWR	1
Exelon	Matagorda or Victoria Counties (TX)	Nov. 2008	Westinghouse AP1000 or GE ESBWR	2
FPL	Not specified	2009	Not specified	1
NRG Energy	South Texas Project	Submitted Sept. 20, 2007	GE ABWR	2
NuStart	Grand Gulf (MS)	2007	GE ESBWR	1
	Bellefonte (AL)	Submitted Oct. 30, 2007	Westinghouse AP1000	2
PPL	Susquehanna (PA)	Not specified	Areva EPR	1
Progress Energy	Harris (NC)	2008	Westinghouse AP1000	2
	Levy County (FL)	2008	Westinghouse AP1000	2
SCE&G	Summer (SC)	2007	Westinghouse AP1000	2
Southern	Vogtle (GA)	Mar. 2008	Westinghouse AP1000	2
TXU	Comanche Peak (TX)	4Q 2008	Mitsubishi US-APWR	2
Total Units				31

Sources: NRC, *Nucleonics Week*, *Nuclear News*, Nuclear Energy Institute, company news releases.

Worldwide Nuclear Power Status

Operating commercial nuclear reactors around the world totaled 443 in 2005, with total installed electric generating capacity of 368 gigawatts. More than 80% of that capacity is in member nations of the Organization for Economic Cooperation and Development (OECD), while slightly more than 10% is in Russia and other former nations of the Soviet bloc. The remainder, about 5%, is in developing countries such as China and India. Nuclear power supplied 22.4% of electricity generated in OECD countries in 2005, 17.0% in the former Soviet countries, and 2.1% in developing countries.²⁴

Unlike the United States, where active construction of new reactors ended in 1996, the rest of the world has continued building nuclear plants, although at a modest pace. Since 1996, about 40 commercial reactors have started up, an average of about four per year. About 30 reactors were permanently closed during that period, although many of them were smaller than the newly started reactors.²⁵

As shown in the following figures, current reactor construction is dominated by Asia. Of the 27 reactors currently under construction around the world, 18 are in Asia, while only five are in Europe, three in the Americas, and one in the Middle East (Iran). Planned or proposed nuclear power plants show a similar trend. Of the 203 potential reactors identified in the following figures, more than half (112) are in Asia, while 44 are in Europe, 40 in the Americas, and seven in the Middle East.

The renewed worldwide interest in nuclear power has led to a possible expansion of the technology to currently non-nuclear nations. Six of the countries that are currently building or formally considering reactor projects — Egypt, Indonesia, Iran, Israel, Malaysia, and Vietnam — have never operated nuclear power plants. Several other non-nuclear countries have also raised the possibility of building nuclear power plants, including Belarus, Libya, Jordan, Nigeria, Qatar, Saudi Arabia, Syria, Thailand, and Turkey.²⁶ (See **Figure 2**, below.)

Nuclear Fuel Services Market

The possible upsurge in worldwide nuclear power plant construction has focused new attention on nuclear fuel production. Chronic worldwide overcapacity in all phases of the nuclear fuel cycle appears to be ending, evidenced by sharply higher prices for uranium and enrichment services. The tightening supplies have sparked plans for new fuel cycle facilities around the world and also renewed concerns about controls over the spread of nuclear fuel technology.

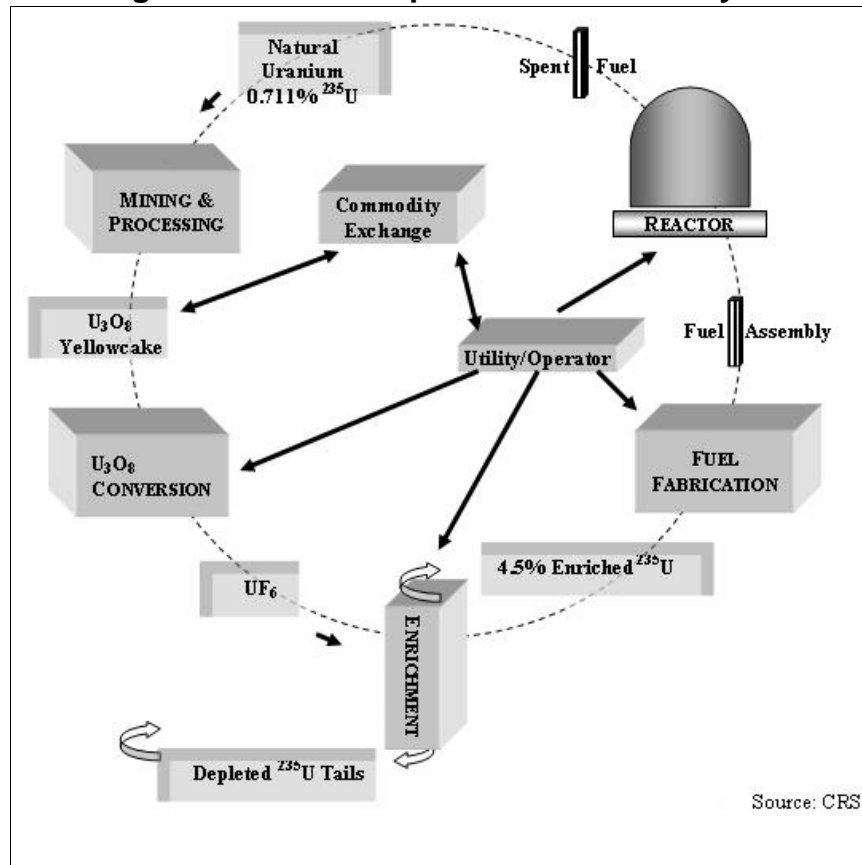
²⁴ International Energy Agency, *World Energy Outlook 2006*, p. 347.

²⁵ World Nuclear Association Reactor Database, at [http://www.world-nuclear.org/reference/reactorsdb_index.php].

²⁶ *Nucleonics Week*, April 19, 2007; BBC Monitoring, April 12, 2007; Dow Jones, April 14, 2007; Associated Press, April 15, 2007; All Africa Global Media, May 25, 2007; XFN Asia, June 12, 2007; *New York Times*, April 16, 2007.

The nuclear fuel cycle begins with mining uranium ore, and upgrading it to yellowcake. Naturally occurring uranium lacks sufficient fissionable ^{235}U to make fuel for commercial light-water reactors, through an enrichment process the concentration of ^{235}U is increased several times above its natural level of 0.7%. A nuclear power plant operator or utility purchases yellowcake and contracts for its conversion to uranium hexafluoride, then enrichment and finally fabrication into fuel elements (**Figure 1**). Commercial enrichment services are available in the United States, Europe, Russia, and Japan. Fuel fabrication services are even more widely available. While waiting for conversion, the yellowcake remains a fungible commodity that can be consigned by the reactor operator to any conversion plant and the product sent to any enrichment plant (within trade restrictions between countries).²⁷ The sale of yellowcake had been informal, until recently when it moved to a more formal commodity transaction basis. The various stages of the nuclear fuel cycle are described below.

Figure 1. The Conceptual Nuclear Fuel Cycle



Yellowcake. Conventionally mined uranium ore (open-pit and underground) is milled, then acid leached to extract uranium oxide. The extract is then filtered, dried, and packaged as uranium yellowcake for shipment to a conversion plant. In-situ leaching avoids the mechanical mining steps by directly injecting solvents into

²⁷ IAEA, *Country Nuclear Fuel Cycle Profiles*, 2nd ed., 2005.

the ore body through wells drilled from the surface. The dissolved uranium is pumped to the surface, where the uranium oxide is similarly processed into yellowcake for shipment.

U.S. uranium reserves are located in Arizona, Colorado, Nebraska, New Mexico, Texas, Utah, Washington, and Wyoming. According to the Energy Information Administration (EIA), five underground mines and five in-situ mines were operating in the United States in 2006. EIA reports 67 million pounds of U_3O_8 were purchased for U.S. nuclear power reactors in 2006, of which 16% was U.S. origin.²⁸ The balance was made up in part by imports and downblended highly enriched uranium (HEU), as discussed further below.

A typical 1,000 MW light water reactor fuel load may require converting and enriching nearly 800,000 lbs. of uranium “yellowcake” (U_3O_8). Approximately 102 million lbs. of yellowcake was produced worldwide in 2004. Worldwide uranium demand in 2004 (the latest statistics available) was an estimated 173 million pounds U_3O_8 .²⁹ The International Atomic Energy Agency (IAEA) projects that the demand for uranium will begin to exceed supply after 2010, and by as much as 10,000 metric tons by 2020.³⁰ IAEA believes that the shortfall could be made up by downblending more HEU released from weapons stockpiles.

Unlike gold or oil commodities, uranium yellowcake had not been offered through a formal market exchange until quite recently. Uranium price indicators had been developed by a small number of private business organizations, such as the World Nuclear Fuel Market (WNFM) and the Ux Consulting Company (UxC), that independently monitor uranium market activities, including offers, bids, and transactions. The price indicators are owned by and proprietary to the business that has developed them.

NAC International (now a USEC Inc. subsidiary) established the World Nuclear Fuel Market (WNFM) to provide uranium price information in 1974. The WNFM membership comprises 79 companies representing 18 countries.³¹ The WNFM provides the uranium price information system (UPIS) for both Western and Russian yellowcake contract prices.³² A quarterly UPIS report presents aggregated

²⁸ U.S. DOE Energy Information Administration, *Uranium Marketing Annual Report*, May 16, 2007, at [<http://www.eia.doe.gov/cneaf/nuclear/umar/umar.html>].

²⁹ U.S. DOE, *Report on the Effect of the Low-Enriched Uranium Delivered Under the HEU Agreement Between the United States and the Government of the Russian Federation on the Domestic Uranium Mining, Conversion, and Enrichment Industries and the Operation of the Gaseous Diffusion Plant*, December 31, 2004.

³⁰ Note: Metric tons is the unit of measurement for uranium fuel. One metric ton is approximately 2,200 pounds. International Atomic Energy Agency, *Management of high enriched uranium for peaceful purposes: Status and trends* (IAEA-TECDOC-1452), June 2005.

³¹ World Nuclear Fuel Market website, at [<http://www.wnfm.com/public/default.htm>].

³² Information on the Uranium Price Information System is available through NAC (continued...)

information based on actual uranium contract price data provided by the 19 UPIS subscribers.³³

The UxC pricing index has been utilized by major nuclear fuel market participants, the federal government, and private business. The UxC yellowcake price was one of only two weekly uranium price indicators that were accepted by the uranium industry, as witnessed by their inclusion in most “market price” sales contracts; that is, sales contracts with pricing provisions that call for the future uranium delivery price to be equal to the market price at or around the time of delivery.

In April 2007, the New York Mercantile Exchange (NYMEX) announced that it had partnered with the UxC to provide financially settled on- and off-exchange traded uranium futures contracts.³⁴ A NYMEX uranium futures contract’s final settlement price is based on the UxC pricing index for yellowcake. Uranium futures contracts are available for trading on Chicago Mercantile Exchange Globex, and for clearing on NYMEX ClearPort.³⁵ The size of each contract is 250 lbs, and prices are quoted in U.S. currency. The final settlement price is the spot month-end price published by UxC.

Uranium is typically mined outside the countries that use it. More than half the world’s production in 2005 came from Canada and Australia, while more than half the world’s commercial reactors are in the United States, France, and Japan.³⁶ But security of uranium supply, while always an underlying policy concern, has rarely been a real problem, because production vastly outstripped demand during the first three decades of the commercial nuclear power era — until about the mid-1980s.³⁷ As a result, a huge overhang of military and civilian stockpiles of uranium helped maintain a worldwide buyers’ market.

Since the mid-1980s, however, world nuclear fuel requirements continued to rise while uranium exploration and production fell. By 2000, as U.S. spot-market prices hit bottom (at about \$7 per pound), the western world’s nuclear fuel requirements were twice the level of production. At that point, commercial stockpiles had been drawn down enough to begin putting pressure on U.S. spot prices, which rose slightly through 2003 and then dramatically (above \$75 per pound)

³² (...continued)

International at (678) 328-1211 or e-mail at gleamon@nacintl.com.

³³ Nine U.S. companies, 10 non-U.S. companies, 12 utilities, four producers, two traders, and one supplier.

³⁴ New York Mercantile Exchange, at [http://www.nymex.com/UX_pre_agree.aspx].

³⁵ CME Globex is a global electronic trading platform for trading futures products. NYMEX ClearPort Clearing provides traders an interface where transactions are posted, margin requirements are calculated, and the transactions are processed by the clearinghouse.

³⁶ Nuclear Energy Agency, *Forty Years of Uranium Resources, Production and Demand in Perspective*, 2006, pp. 10-11.

³⁷ World Nuclear Association, *Uranium Markets*, March 2007, at [<http://www.world-nuclear.org/info/inf22.html>]

by 2007. The spot price represents about 20% of the market but provides an indicator of future contracts, which usually run 3-7 years.³⁸

Despite low worldwide exploration expenditures since the mid-1980s caused by oversupply and low prices, estimated uranium resources have trended upward over the long term. As a result, according to the OECD Nuclear Energy Agency (NEA), known conventional resources have averaged 45 years of supply during the past 20 years, despite steadily increasing annual world uranium requirements, currently about 70,000 metric tons. “Taken together the lessons of the past provide confidence that uranium resources will remain adequate to meet projected demands even were requirements to significantly increase,” according to NEA.³⁹

Conversion. In the conversion process, the yellowcake is purified, chemically reacted with hydrofluoric acid to form uranium hexafluoride (UF₆) gas, and then transferred into cylinders where it cools and condenses to a solid. Uranium hexafluoride contains two isotopes of uranium — heavier ²³⁸U and lighter fissionable ²³⁵U, which makes up ~0.7% of uranium by weight. The annual U.S. demand for yellow cake conversion is approximately 22,000 metric tons uranium (MTU). After conversion, the uranium hexafluoride is ready for enrichment.

Five commercial conversion companies operate worldwide — in the United States, Canada, France, the United Kingdom, and Russia (**Table 2**). ConverDyn in Metropolis, IL, the only conversion plant operating in the United States, produces 14,000 MTU annually.

Table 2. Commercial UF₆ Conversion Facilities
(metric tons uranium/year)

Country	Company	Facility	Capacity
Canada	Cameco	Port Hope	12,500
China	CNCC	Lanzhou	1,500
France	Comurhex	Peirrelatte 1 Peirrelatte 2	14,000 350
Russian Federation	Minatom	Angarsk Tomsk	20,000 10,000
U.K.	BNFL	Springfields Line 4	6,000
U.S.	Converdyn	Metropolis	14,000

Source: IAEA Country Nuclear Fuel Cycle Profiles, 2nd ed.

Enrichment. For use as fuel in light water reactors, ²³⁵U must be enriched above its natural ore concentration. By heating yellowcake (UF₆) to turn it into a gas,

³⁸ Ibid.

³⁹ Nuclear Energy Agency, *op. cit.*, p. 13.

the enrichment process can take advantage of the slight difference in atomic mass between ^{235}U and ^{238}U . The typical enrichment process requires about 10 lbs of uranium U_3O_8 to produce 1 lb of low enriched uranium hexafluoride (UF_6) product.

About 90% of the world's reactors (all except heavy water reactors) require enriched uranium fuel. More than 90% of those uranium enrichment requirements are supplied by facilities in the United States (including diluted weapons material), Russia, France, Great Britain, Germany, and the Netherlands. The remainder comes from Japan, China, and Brazil. Thirty-one countries currently operate commercial nuclear power plants. Most countries, therefore, rely on enrichment services outside their borders. An enrichment plant to serve a country with only a few reactors would appear economically nonviable, given that a single large enrichment plant can supply up to 25% of the world market (currently estimated at 45 million separative work units, or SWUs).⁴⁰

Commercial uranium enrichment employs either gaseous diffusion or high speed centrifuge. In gaseous diffusion, a thin semiporous barrier holds back more of the heavier ^{238}U than the lighter ^{235}U . A series of cascading diffusers successively enriches the ^{235}U concentration. Centrifuge enrichment spins the uranium hexafluoride gas at ultra-high speeds to separate the lighter ^{235}U . A series of cascading centrifuges successively enriches the gas in ^{235}U . Final enrichment will vary depending on the requirements of a specific reactor, normally up to about 4%.

Gaseous diffusion technology was first developed in the United States and later adopted by France and Britain. It is more energy-intensive than the newer centrifuge enrichment process. However, the legacy gaseous diffusion plants currently operating in the United States and France have higher capacities than the newer centrifuge enrichment plants.

Uranium enrichment services are sold in kilograms (kg) or metric tons (1,000 kg) separative work units (SWU), which is a measure of the amount of work needed (in the thermodynamic sense) to enhance the ^{235}U concentration. The number of SWUs required to produce fuel depends on several factors: the quantity of fuel required, level of enrichment required, the initial enrichment of the feed (0.711% in the case of natural uranium), and the "tails assay," which is the ^{235}U concentration remaining in the depleted processing stream. For example, to produce 1 kg of uranium enriched to 3% ^{235}U , at a tails assay of 0.2% ^{235}U , 4.3 kg-SWU are used to process 5.5 kg of natural uranium.⁴¹ The price of yellowcake is an important factor in enrichment demand. Under high price conditions, it may be economically preferable to expend more SWUs enriching a lesser quantity of yellowcake, thus leaving a lower tails assay. In 2005, the approximately 53 million lbs of yellowcake contracted for enrichment required 11 million SWUs. Higher uranium prices also leads to recycling stockpiles of higher assay tails back through enrichment.

⁴⁰ Ruthane Neely and Jeff Combs, "Diffusion Fades Away," *Nuclear Engineering International*, September 2006, p. 24.

⁴¹ Thomas L. Neff, *The International Uranium Market*, Ballinger Publishing Co., 1984

Nuclear plant operators can buy uranium yellowcake and have it converted and enriched, or buy low-enriched uranium (LEU). Commercial enrichment services are offered by a number of international sources (**Table 3**) making a up a worldwide annual capacity of 47,855 metric tons SWU. In 2006, U.S. nuclear plant operators contracted five companies worldwide to enrich 57 million pounds of yellowcake. Of the approximately 13 million SWU required, only 12% of the needed enrichment could be provided in the U.S.⁴²

⁴² EIA.

Table 3. Operating Commercial Uranium Enrichment Facilities
(metric tons SWU/year)

Facility Name	Country	Process	Capacity
Paducah Gaseous Diffusion	United States	Gaseous Diffusion	11,300
Eurodif (Georges Besse)	France	Gaseous Diffusion	10,800
Ekaterinburg (Sverdlovsk-44)	Russian Federation	Centrifuge	7,000
Siberian Chemical Combine (Seversk)	Russian Federation	Centrifuge (downblended)	4,000
Urenco Capenhurst	United Kingdom	Centrifuge	4,000
Krasnoyarsk	Russian Federation	Centrifuge	3,000
Urenco Nederland	Netherlands	Centrifuge	2,900
Urenco Deutschland	Germany	Centrifuge	1,800
Rokkasho Uranium Enrichment Plant	Japan	Centrifuge	1,050
Angarsk	Russian Federation	Centrifuge	1,000
Lanzhou 2	China	Centrifuge	500
Shaanxi Uranium Enrichment Plant	China	Centrifuge	500
Kahuta	Pakistan	Centrifuge	5
Total			47,855

Source: International Atomic Energy Agency, Nuclear Fuel Cycle Information System.

The U.S. DOE had operated gaseous diffusion enrichment plants in Oak Ridge, TN, Paducah, KY, and Portsmouth, OH, to produce high-enriched uranium used in the nuclear weapons program. The plants later produced low-enriched uranium for commercial nuclear power around the world, although production at the Oak Ridge K-25 enrichment site ceased in 1985. The Energy Policy Act of 1992 established the United States Enrichment Corporation (USEC) as a government-owned corporation to take over DOE's uranium enrichment services business. The corporation was privatized as USEC Inc. in 1998. In 2001, USEC ceased uranium enrichment operations in Portsmouth and consolidated operations in Paducah. The Paducah gaseous diffusion plant is the only operating enrichment facility in the United States. In 2004, USEC announced plans to build the American Centrifuge Plant on the site of the Portsmouth, Ohio gaseous diffusion plant. The new gas centrifuge enrichment plant will expand to 11,500 centrifuges with a capacity of 3.8 million SWU.⁴³ USEC

⁴³ *USEC to Site American Centrifuge Plant in Piketon, Ohio — Technology Expected to Be World's Most Efficient for Enriching Nuclear Fuel*, at [http://www.usec.com/v2001_02/Content/News/NewsTemplate.asp?page=/v2001_02/Content/News/NewsFiles/01-12-04.htm].

currently supplies approximately 51% of the U.S. demand for enrichment services, mostly with blended-down Russian HEU, as discussed below.

Urenco, a joint Dutch, German, and British enrichment consortium, was set up in the 1970s following the signing of the Treaty of Almelo. Urenco operates enrichment plants in Germany, the Netherlands, and the United Kingdom to supply customers in Europe, North America, and East Asia. Its U.S. affiliate, Louisiana Energy Services, has begun constructing the gas centrifuge National Enrichment Facility (NEF) in New Mexico.⁴⁴ The NEF is expected to produce 3 million SWUs annually when it reaches full operational capacity in 2013 — meeting approximately 25% of the current U.S. demand.⁴⁵ In 2006, Urenco estimated that it provided around 23% of the world market share in enrichment services.

Areva operates the Eurodif gaseous diffusion production plant (located on the Tricastin nuclear site in France) to enrich uranium for some 100 nuclear reactors in France and throughout the world.⁴⁶ Areva nc Inc. provides toll conversion services and uranium yellowcake through its subsidiary Comurhex.

Under the 1993 U.S.-Russian Federation Megatons to Megawatts program, highly enriched uranium from dismantled Russian nuclear warheads is converted into low-enriched uranium fuel for use in commercial U.S. nuclear power plants.⁴⁷ The HEU Agreement, as it is known, provides for the purchase over 20 years of 500 metric tons highly enriched uranium downblended to commercial grade low-enriched uranium (delivered as UF₆). The agreement provides about 46% of the current U.S. demand for enrichment.

The world uranium enrichment industry is currently undergoing a technological transformation from gaseous diffusion to centrifuges, primarily because centrifuges need only a fraction of the energy required by gaseous diffusion. In 1996, 57% of the world's commercial enrichment came from gaseous diffusion plants, a level that dropped to 35% in 2006. As noted above, the United States' only currently operating enrichment facility, in Paducah, KY, is to be replaced by 2011 with a centrifuge plant in Portsmouth, OH. The world's only other operating gaseous diffusion plant, at Areva's Tricastin site in France, is to be replaced by a centrifuge plant by around 2012.⁴⁸

Fuel Fabrication. Like enrichment, fuel fabrication is a specialized service rather than a commodity transaction. The now low-enriched uranium (UF₆) undergoes one final process, converting to uranium dioxide (UO₂), before the final stage of fuel fabrication. It is then sintered into pellets and loaded into zirconium alloy tubes (fuel rods) about 12-15 feet long and half an inch in diameter. The fuel

⁴⁴ URENCO [<http://www.urengo.com/fullArticle.aspx?m=1371>].

⁴⁵ URENCO [<http://www.urengo.com/fullArticle.aspx?m=1371>].

⁴⁶ AREVA [http://www.aveva-nc.com/servlet/ContentServer?pagename=cogema_en%2FPage%2Fpage_site_prod_full_template&c=Page&cid=1039482707079].

⁴⁷ [<http://www.usec.com>].

⁴⁸ Ibid.

rods are bundled into fuel assemblies, which vary from less than 100 to as many as 300 rods apiece.

Fuel fabrication services are offered by 16 suppliers operating in 18 countries at around 34 facilities. In 2002, IAEA estimated that worldwide fabrication capacity of 19,000 tons (fuel assemblies and elements) exceeded the demand by 53%.⁴⁹ The oversupply had existed for many years, and, as a consequence, facilities were shut down and ownership was consolidated.

Essentially all U.S. fabrication demand is met by three companies providing fabrication service at four facilities: Framatome ANP Inc. in Lynchburg, VA, and Richland, WA; Global Nuclear Fuel in Wilmington, NC; and Westinghouse Electric in Columbia, SC. About 30 other nuclear fuel fabrication facilities are in operation elsewhere in the world.⁵⁰

Final Stages of the Fuel Cycle

The final stages of the nuclear fuel cycle take place after nuclear fuel assemblies have been loaded into a reactor. In the reactor, the uranium 235 (^{235}U) splits, or fissions, releasing energy, neutrons, and fission products (highly radioactive fragments of ^{235}U nuclei). The neutrons may cause other ^{235}U nuclei to fission, creating a nuclear chain reaction. Some neutrons are also absorbed by ^{238}U nuclei to create plutonium 239 (^{239}Pu), which itself may then fission.

After several years in the reactor, fuel assemblies will build up too many neutron-absorbing fission products and become too depleted in fissile ^{235}U to efficiently sustain a nuclear chain reaction. At that point, the assemblies are considered spent nuclear fuel and removed from the reactor. Spent fuel typically contains about 1% ^{235}U , 1% plutonium, 4% fission products, and the remainder ^{238}U .

The last stage of the fuel cycle, after spent fuel is removed from a reactor, has proved highly contentious. One option is to directly dispose of spent fuel in a deep geologic repository to isolate it for the hundreds of thousands of years that it may remain hazardous. The other option is to reprocess the spent fuel to separate the uranium and plutonium for use in new fuel. Supporters of reprocessing, or recycling, contend that it could greatly reduce the volume and longevity of nuclear waste while vastly expanding the amount of energy extracted from the world's uranium resources. Opponents contend that commercial use of separated plutonium — a key material in nuclear weapons as well as reactor fuel — poses a nuclear weapons proliferation threat.

Commercial-scale spent fuel reprocessing is currently conducted in France, Britain, and Russia. The ^{239}Pu they produce is blended with uranium to make mixed-oxide (MOX) fuel, in which the ^{239}Pu largely substitutes for ^{235}U . Two French reprocessing plants at La Hague can each reprocess up to 800 metric tons of spent

⁴⁹ IAEA, Country Nuclear Fuel Cycle Profiles, 2nd ed.

⁵⁰ Nuclear Engineering International, *2007 World Nuclear Industry Handbook*, p. 207.

fuel per year, while Britain's THORP facility at Sellafield has a capacity of 900 metric tons per year. Russia has a 400-ton plant at Ozersk, and Japan is building an 800-ton plant at Rokkasho to succeed a 90-ton demonstration facility at Tokai Mura. Britain and France also have older plants to reprocess gas-cooled reactor fuel, and India has a 275-ton plant.⁵¹ About 200 metric tons of MOX fuel is used annually, about 2% of new nuclear fuel,⁵² equivalent to about 2,000 metric tons of mined uranium.⁵³

However, the benefits of reprocessing spent fuel from today's nuclear power plants are modest. Existing commercial light water reactors use ordinary water to slow down, or "moderate," the neutrons released by the fission process. The relatively slow (thermal) neutrons are highly efficient in causing fission in certain isotopes of heavy elements, such as ^{235}U and ^{239}Pu .⁵⁴ Therefore, fewer of those isotopes are needed in nuclear fuel to sustain a nuclear chain reaction. The downside is that thermal neutrons cannot efficiently induce fission in more than a few specific isotopes. In today's commercial reactors, therefore, the buildup of non-fissile plutonium and other isotopes sharply limits the number of reprocessing cycles before the recycled fuel can no longer sustain a nuclear chain reaction and must be stored or disposed of.

In contrast, "fast" neutrons, which have not been moderated, are less effective in inducing fission than thermal neutrons but can induce fission in all actinides, including all plutonium isotopes. Therefore, nuclear fuel for a fast reactor must have a higher proportion of fissionable isotopes than a thermal reactor to sustain a chain reaction, but a larger number of different isotopes can constitute that fissionable proportion.

A fast reactor's ability to fission all actinides (actinium and heavier elements), makes it theoretically possible to repeatedly separate those materials from spent fuel and feed them back into the reactor until they are entirely fissioned. Fast reactors are also ideal for "breeding" the maximum amount of ^{239}Pu from ^{238}U , eventually converting virtually all of natural uranium to useable nuclear fuel.⁵⁵

⁵¹ World Nuclear Association, *Processing of Used Nuclear Fuel for Recycle*, March 2007, at [<http://www.world-nuclear.org/info/inf69.html>].

⁵² World Nuclear Association, *Mixed Oxide Fuel (MOX)*, November 2006, at [<http://www.world-nuclear.org/info/inf29.html>].

⁵³ World Nuclear Association, *Uranium Markets*, March 2007.

⁵⁴ Isotopes are atoms of the same chemical element but with different numbers of neutrons in their nuclei.

⁵⁵ The core of a breeder reactor is configured so that more fissile ^{239}Pu is produced from ^{238}U than the amount of fissile material initially loaded into the core that is consumed (^{235}U or ^{239}Pu). In a breeder, therefore, enough fissile material could be recovered through reprocessing to refuel the reactor and to provide fuel for additional breeders. The core of a fast reactor can also be configured to produce less ^{239}Pu than fissile material consumed, if the primary goal is to eliminate ^{239}Pu from spent fuel. In that case, much less ^{238}U ultimately would be converted to ^{239}Pu and therefore less total energy produced from a given

(continued...)

Current reprocessing programs are generally viewed by their proponents as interim steps toward a commercial nuclear fuel cycle based on fast reactors.

Waste Disposal and Energy Security

Reprocessing of spent fuel from fast breeder reactors has long been the ultimate goal of nuclear power supporters. As noted above, fast reactors (operated either as breeders or non-breeders) can eliminate plutonium from nuclear waste and greatly extend uranium supplies. But opponents contend that such potential benefits are not worth the costs and nonproliferation risks.

Removing uranium from spent nuclear fuel through reprocessing would eliminate most of the volume of radioactive material requiring disposal in a deep geologic repository. In addition, the removal of plutonium and conversion to shorter-lived fission products would eliminate most of the long-term (post-1,000 years) radioactivity in nuclear waste. But the waste resulting from reprocessing would have nearly the same short-term radioactivity and heat as the original spent fuel, because the reprocessing waste consists primarily of fission products, which generate most of the radioactivity and heat in spent fuel. Because heat is the main limiting factor on repository capacity, conventional reprocessing would not provide major disposal benefits in the near term.

DOE is addressing that problem with a proposal to further separate the primary heat-generating fission products — cesium 137 and strontium 90 — from high level waste for separate storage and decay over several hundred years. That proposal would greatly increase repository capacity, although it would require an alternative secure storage system for the cesium and strontium that has yet to be designed.

Energy security has been a primary driving force behind the development of nuclear energy, particularly in countries such as France and Japan that have few natural energy resources. Recent cutoffs in oil and gas have underscored the instability of oil and gas supply, which could be mitigated by nuclear energy. For example, in 2006, a natural gas price dispute between Russia and Ukraine resulted in a temporary cutoff of natural gas to Western and Central Europe; in 2007, price disputes between Russia and Azerbaijan and Belarus caused a temporary cutoff in oil to Russia from Azerbaijan and in oil from Russia to Germany, Poland, and Slovakia. Moreover, temporary production shutdowns in the Gulf of Mexico and the Trans-Alaskan pipeline, instability in Nigeria, and nationalization of oil and gas fields in Bolivia in 2006, have all raised concerns about oil and gas supplies and worldwide price volatility. Relative to gas and oil, the ability to stockpile uranium is widely seen as offering greater assurances of weathering potential cutoffs.

Worldwide uranium resources are generally considered to be sufficient for at least several decades. Uranium supply is highly diversified, with uranium mining spread across the globe, while uranium conversion, enrichment, and fuel fabrication are more concentrated in a handful of countries. But because most reactors around

⁵⁵ (...continued)
amount of natural uranium.

the world rely at least partly on foreign sources of uranium and nuclear fuel services, nuclear reactors nearly everywhere face some level of supply vulnerability. To mitigate such concern, countries such as China, India and Japan are seeking to secure long-term uranium contracts to support nuclear expansion goals. Efforts are underway to establish an international nuclear fuel bank attempt to inject greater certainty in fuel supplies, as discussed in the next section.

Ultimately, only the development of breeder reactors and reprocessing could provide true nuclear energy independence. This remains the long-term goal of resource-poor France and Japan, and Russia as well, although their research and development programs have faced numerous obstacles and schedule slowdowns.

Proposals on the Fuel Cycle⁵⁶

Proposals on limiting access to the full nuclear fuel cycle have ranged from a formal commitment to forswear enrichment and reprocessing technology, to a de facto approach in which a state does not operate fuel cycle facilities but makes no explicit commitment to give them up, to no restrictions at all. All of these proposals aim to persuade countries not to develop their own fuel production capabilities by providing economically attractive alternatives that allay concerns about politically-motivated interruption to fuel supply. Most proposals focus on this front-end problem, dealing with fuel supply and production issues. The U.S. Global Nuclear Energy Partnership (GNEP) envisions giving incentives on the back-end of the fuel cycle as well by offering management of spent fuel and toxic byproducts.

President Bush's 2004 Proposal

In a speech at the National Defense University on February 11, 2004, President Bush said the world needed to “close a loophole” in the NPT that allows states to legally acquire the technology to produce nuclear material which could be used for a clandestine weapons program. To remedy this, he proposed that the forty members of the Nuclear Suppliers Group (NSG) should “refuse to sell enrichment and reprocessing equipment and technologies to any state that does not already possess full-scale, functioning enrichment and reprocessing plants.”⁵⁷ President Bush also called on the world's leading nuclear fuel services exporters to “ensure that states have reliable access at reasonable cost to fuel for civilian reactors, so long as those states renounce enrichment and reprocessing.”

In wake of the A.Q. Khan network revelations (also highlighted in the February 2004 speech), the international community had a renewed interest in addressing this

⁵⁶ This section was prepared by Mary Beth Nikitin (Analyst in WMD Nonproliferation), Sharon Squassoni (Specialist in National Defense), and Jill Parillo (Research Associate) in the Foreign Affairs, Defense, and Trade Division, and Anthony Andrews (Specialist in Energy Policy) in the Resources, Science, and Industry Division.

⁵⁷ “President Announces New Measures to Counter the Threat of WMD,” February 11, 2004, at [<http://www.whitehouse.gov/news/releases/2004/02/20040211-4.html>].

quandary. Since 2004, the Group of Eight (G-8) Nations have announced a year-long suspension of any such transfers at their annual summit meetings, and international study groups have been formed to try and find agreement on a more permanent solution to the problem.⁵⁸

President Bush's 2004 proposal is the only one that calls for countries to explicitly "renounce" pursuit of enrichment or reprocessing technologies in exchange for reliable access to nuclear fuel. It was meant to disarm advocates of indigenous fuel cycle development of the argument that only indigenous supply is secure. There has been little agreement on President Bush's proposals. Many non-nuclear weapon states see this as an attempt to limit their inalienable right to the use of peaceful nuclear energy under Article IV of the NPT and are not willing to consider limits on peaceful nuclear technologies until more progress on nuclear disarmament has been made.

Key questions about implementation of this proposal remain unanswered. For example, who is included in the group of supplier states and how is "full-scale, functioning plants" defined? Would Iran's enrichment program qualify today, even if it did not back in 2004? And what about non-NPT states with the full fuel cycle as part of their weapons programs? Also, how would related technologies be treated? For example, would restrictions also apply to post-irradiation experiments on spent nuclear fuel, which yield significant data about reactor operations, but can also contribute to knowledge about reprocessing for weapons purposes? Since 2004, delay in defining these terms appears to have provided an incentive for some states, such as Canada, South Africa, Argentina, and Australia, to expedite their pursuit of a full operational enrichment capability so as not to be excluded when and if such a division between fuel cycle haves and have-nots is made.

Following President Bush's 2004 speech, NSG members discussed how they might implement such restrictions. Since the 1970s, NSG members have adhered to an informal restriction on transferring enrichment, reprocessing, and heavy water technology to states outside the NSG. France suggested one potential approach, which most states reportedly have endorsed except for the United States. The French proposal laid out a set of criteria that recipient states would first need to meet, including the following:

- Member of the NPT in full compliance.
- Comprehensive safeguards agreement and Additional Protocol in force.
- No breach of safeguards obligations, no IAEA Board of Governors decisions taken to address lack of confidence over peaceful intentions.

⁵⁸ See Paragraph 13 of the Heiligendamm Statement on Non-Proliferation, G8 Summit 2007, at [http://www.g-8.de/Content/EN/Artikel/___g8-summit/anlagen/heiligendamm-statement-on-non-proliferation.property=publicationFile.pdf].

- Adherence to NSG Guidelines.
- Bilateral agreement with the supplier that includes assurances on non-explosive uses, effective safeguards in perpetuity, and retransfer.
- Commitment to apply international standards of physical protection.
- Commitment to IAEA safety standards.

The NSG also discussed including more subjective criteria in a decision to supply a state with fuel cycle technology such as general conditions of stability and security, potential negative impact on the stability and security of the recipient state, and whether there is a credible and coherent rationale for pursuing enrichment and reprocessing capability for civil nuclear power purposes.

No consensus has been reached on how to define these criteria and a number of questions remain. For example, it is clear from these requirements that states outside the NPT — such as India, Pakistan, and Israel — would be prohibited from reprocessing and enrichment cooperation with NSG members (which may account for U.S. rejection of the approach). To add further complications, the nuclear cooperation agreement (so-called 123 Agreement) between the US and India signed in July 2007 provides consent in principle for India to reprocess U.S. spent fuel and agreement in principle to transfer enrichment and reprocessing-related technology to India, pursuant to an amendment to the agreement. These two details suggest that India is a reprocessing technology holder, despite not having its reprocessing facilities under comprehensive IAEA safeguards, and call into question criteria for distinguishing between states that should receive assistance and those that should not, particularly since India is neither a party to the NPT nor an NSG member.

In summary, President Bush's proposal as put forth in 2004 faces significant challenges in implementation, given the prevailing views against restrictions, and the lack of a consensus within the NSG on how to proceed.

El Baradei Proposal

In anticipation of resistance to a new arrangement where some states possess this processing technology and some are not allowed to, IAEA Director General Mohamed ElBaradei proposed a 3-pronged approach to limiting the processing of weapon-usable material (separated plutonium and high-enriched uranium) in civilian nuclear fuel cycles.⁵⁹ First, he would place all enrichment and reprocessing facilities under multinational control. Second, he would develop new nuclear technologies that would not produce weapons-usable fissile material — in other words, “the holy grail” of a proliferation-resistant fuel cycle. In his October 2003 article in the *Economist* where he laid out these ideas, ElBaradei maintained, “This is not a futuristic dream; much of the technology for proliferation-resistant nuclear-energy

⁵⁹ “Towards a Safer World,” at [<http://f40.iaea.org/worldatom/Press/Statements/2003/ebTE20031016.shtml>].

systems has already been developed or is actively being researched.” Third, ElBaradei proposed considering “multinational approaches to the management and disposal of spent fuel and radioactive waste.” ElBaradei did not place any nonproliferation requirements on participation, but instead suggested that the system “should be inclusive; nuclear-weapon states, non-nuclear-weapon states, and those outside the current non-proliferation regime should all have a seat at the table.” Further, he noted that a future system should achieve full parity among all states under a new security structure that does not depend on nuclear weapons or nuclear deterrence.

IAEA Experts Group/INFCIRC/640

In February 2005, an Expert Group commissioned by IAEA Director General ElBaradei presented a report, “Multilateral Approaches to the Nuclear Fuel Cycle.”⁶⁰ The Expert Group studied several possible approaches to securing the operation of proliferation-sensitive nuclear fuel cycle activities (uranium enrichment, reprocessing and spent fuel disposal, and storage of spent fuel) and analyzed the incentives and disincentives for states to participate. The report reviewed relevant past and present experience. The Group’s suggested approaches included the following:

- Reinforce existing market mechanisms by providing additional supply guarantees by suppliers and/or the IAEA (fuel bank).
- Convert existing facilities to multinational facilities.
- Create co-managed, jointly owned facilities.

The Group concluded that “in reality, countries will enter into multilateral arrangements according to the economic and political incentives and disincentives offered by these arrangements.”⁶¹ The report noted that no legal framework existed for requiring states to join supply assurance arrangements.

In September 2006, the IAEA sponsored a conference entitled “New Framework for the Utilization of Nuclear Energy in the 21st Century: Assurances of Supply and Non-Proliferation,” which addressed proposals to provide fuel assurances. The IAEA presented a report on fuel assurance options at the June 2007 Board of Governors meeting analyzing the various proposals put forth to date.⁶² A potential framework for nuclear supply assurances could have three stages: (1) existing market arrangements; (2) back-up commitments by suppliers in case of a politically motivated interruption of supply if nonproliferation criteria are met; (3) a physical

⁶⁰ “Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report submitted to the Director General of the International Atomic Energy Agency,” February 22, 2005, (INFCIRC/640). Available at [<http://www.iaea.org/Publications/ocuments/Infcircs/2005/infirc640.pdf>].

⁶¹ *Ibid.*, p. 98.

⁶² International Atomic Energy Agency, *Possible New Framework for the Utilization of Nuclear Energy: Options for Assurance of Supply of Nuclear Fuel*, June 2007.

LEU material reserve.⁶³ The report emphasizes that participation in these arrangements should be voluntary, that progress on this question will be incremental and that many options should be explored to give consumer states sufficient choices to meet their needs. The report is still under discussion by IAEA Board members.

Putin Initiative

In January 2006, Russian President Vladimir Putin proposed four kinds of cooperation: creation of international uranium-enrichment centers (IUECs), international centers for reprocessing and storing spent nuclear fuel, international centers for training and certifying nuclear power plant staff, and an international research effort on proliferation-resistant nuclear energy technology. The international fuel cycle centers would be under joint ownership and co-management. They would be commercial joint ventures (that is, no state financing), with advisory boards consisting of government, industry, and IAEA professionals. The IAEA would not have a vote on these boards, but would play an advisory role, while also certifying the fuel provision commitments. As part of an open joint-stock company, IUEC participants would receive dividends from IUEC profits.

Recipient countries under Putin's proposal would receive fuel cycle services, but access to sensitive technology would stay in the hands of the supplier state. Russia has offered a similar arrangement to Iran — to jointly enrich uranium on Russian territory. Iran has not yet accepted this offer, but it is still part of ongoing negotiations with Iran over its nuclear program. Russia has also made the return of spent fuel from Bushehr a condition of supply, so that no plutonium can be extracted from the spent fuel.⁶⁴

As a first step, Russia has created a model International Uranium Enrichment Center (IUEC) at Angarsk (approximately 3,000 miles east of Moscow). Kazakhstan is the first partner. The Angarsk IUEC began operation on September 5, 2007. Ukraine, Armenia, Mongolia, the Republic of Korea and Japan have also expressed interest in participating in the Angarsk arrangement. France is reportedly also considering establishing a similar IUEC on its territory.⁶⁵ Press reports have also indicated that Turkey is interested in hosting an IUEC.⁶⁶

To join the Angarsk IUEC, countries must agree that the material be used for “nuclear energy production” and must receive all of their enrichment supply from the

⁶³ Tariq Rauf, “Realizing Nuclear Fuel Assurances: Third Time's the Charm,” Presentation to the Carnegie International Nonproliferation Conference, June 24, 2007, at [http://www.carnegieendowment.org/files/fuel_assurances_rauf.pdf].

⁶⁴ “The Last Word: Sergei Kirienko,” *Newsweek*, February 20, 2006 issue, at [<http://www.msnbc.msn.com/id/11299203/site/newsweek/>].

⁶⁵ “France: International partnership part of new enrichment business,” *Nuclear Fuel*, September 24, 2007.

⁶⁶ “Nuke Plans Light Up,” *Turkish Daily News*, January 15, 2008.

IUEC.⁶⁷ The IUEC is “chiefly oriented to States not developing uranium enrichment capabilities on their territory.”⁶⁸ The type of safeguards for the envisioned international fuel cycle center has yet to be determined by the IAEA, but are under discussion.⁶⁹ Ideally, Russia would like the nuclear fuel being provided to non-nuclear weapon states to be fully safeguarded by the IAEA. Russia has reportedly requested that safeguards apply to the perimeter of the Angarsk facility as well as to the material stockpile (not within the facility). Russia, as a nuclear weapon state under the NPT, has a voluntary safeguards agreement which allows, but does not require, inspections.

Six Country Concept

In May 2006, six governments — France, Germany, the Netherlands, Russia, the United Kingdom, and the United States — proposed a “Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel”⁷⁰ (referred to here as the Six Country Concept). This proposal reportedly developed from a U.S. initiative following President Bush’s 2004 proposal. It would not require states to forgo enrichment and reprocessing, but participation would be limited to those states that did not currently have enrichment and reprocessing capabilities.

The Six Country Concept calls for a multi-tiered backup mechanism to ensure the supply of low enriched uranium (LEU) for nuclear fuel. The proposal would work as follows: (1) A commercial supply relationship is interrupted for reasons other than nonproliferation; (2) The recipient or supplier state can approach the IAEA to request backup supply; (3) The IAEA would rule out commercial or technical reasons for interruption (to avoid a market disruption) and assess whether the recipient meets the following qualifications: it must have a comprehensive safeguards agreement and Additional Protocol in force; it must adhere to international nuclear safety and physical protection standards; and it is not pursuing sensitive fuel cycle activities (which are not defined); (4) The IAEA would facilitate new arrangements with alternative suppliers.

Two mechanisms were proposed to create multiple tiers of assurances: including a standard backup provision in commercial contracts, and establishing reserves of LEU (not necessarily held by the IAEA, but possibly with rights regarding the use of the reserves). The Six Country Concept specifically mentioned the 17 tons of U.S.

⁶⁷ “Russia’s Angarsk international enrichment center open for business,” *Nuclear Fuel*, September 24, 2007.

⁶⁸ “Communication received from the Resident Representative of the Russian Federation to the IAEA on the Establishment, Structure and Operation of the International Uranium Enrichment Centre,” INFCIRC/708, June 8, 2007.

⁶⁹ “IAEA eyes monitoring Russian uranium enrichment facilities,” *Kyodo World Service*, October 10, 2007.

⁷⁰ “Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel,” Proposal as sent to the IAEA from France, Germany, the Netherlands, Russia, Ireland, and the United States, May 31, 2006, IAEA GOV/INF/2006/10. Available at [http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2006/cn147_ConceptRA_NF.pdf].

HEU declared in September 2006 to be excess to defense needs, which would be converted to LEU and held in reserve to support fuel supply assurances.⁷¹ According to U.S. Ambassador Gregory Schulte, any such reserve in the United States would be kept under national control.⁷² Stringent U.S. requirements on U.S.-origin material, pursuant to the 1954 Atomic Energy Act (as amended), may limit the attractiveness of that material for some states. Such requirements include safeguards in perpetuity, prior consent for enrichment and reprocessing, and the right of return should a non-nuclear weapon state detonate a nuclear explosive device.⁷³

The Six Country Concept addressed several future options, all of which are longer term in nature. They include providing reliable access to existing reprocessing capabilities for spent fuel management; multilateral cooperation in fresh fuel fabrication and spent fuel management; international enrichment centers; and new fuel cycle technology development that could incorporate fuel supply assurances.

Nuclear Threat Initiative Fuel Bank

In September 2006, former Senator Sam Nunn, Co-Chairman of the Nuclear Threat Initiative (NTI),⁷⁴ announced NTI's pledge of \$50 million as seed money to create a low-enriched uranium stockpile owned and managed by the IAEA. NTI believes that the establishment of such an LEU reserve would assure an international supply of nuclear fuel on a non-discriminatory, non-political basis to recipient states. As Senator Nunn said in his speech announcing the pledge, "We envision that this stockpile will be available as a last-resort fuel reserve for nations that have made the sovereign choice to develop their nuclear energy based on foreign sources of fuel supply services- and therefore have no indigenous enrichment facilities."⁷⁵

Provision of the NTI money is contingent on the IAEA taking the necessary preparatory actions to establish the reserve and on contribution of an additional \$100 million or an equivalent value of LEU, by one or more IAEA Member States.⁷⁶ No other conditions have been set by NTI — policy questions are meant to be solved by

⁷¹ Assistant Secretary of Energy Dennis Spurgeon, Remarks at an IAEA Special Event on "Assurances of Nuclear Supply and Nonproliferation," September 19, 2006. Available at [<http://energy.gov/news/4173.htm>].

⁷² "News Analysis: The Growing Nuclear Fuel-Cycle Debate," Arms Control Today, November 2006. Available at [http://www.armscontrol.org/act/2006_11/NAFuel.asp].

⁷³ See CRS Report RL33016, *U.S. Nuclear Cooperation With India: Issues for Congress*, by Sharon Squassoni, for additional detail on the requirements contained in Section 123 of the Atomic Energy Act.

⁷⁴ Nuclear Threat Initiative is a private organization founded in 2001 by Mr. Ted Turner and former Senator Sam Nunn. It is now classified as a 501(c)3 public charity.

⁷⁵ New Framework for the Utilization of Nuclear Energy in the 21st Century: Assurances of Supply and Nonproliferation, IAEA Special Event, Speech by Sam Nunn, September 19, 2006, at [<http://www.nti.org>].

⁷⁶ Nuclear Threat Initiative Commits \$50 million to Create IAEA Nuclear Fuel Bank, International Atomic Energy Agency Press Release, September 19, 2006. Available at [http://www.nti.org/c_press/release_IAEA_Fuelbank_091906.pdf].

the IAEA and member states. Key issues still to be determined include the reserve's content, location, criteria for determining access to the stocks including safety and export control standards, the fuel's pricing, and how the fuel in reserve would be fabricated into the appropriate fuel type for the customer's reactor.⁷⁷

Several bills before Congress support the establishment of an international fuel bank. On April 18, 2007, Senator Lugar introduced S. 1138 in the Senate, the Nuclear Safeguards and Supply Act of 2007. This bill would make it U.S. policy to "discourage the development of additional enrichment and reprocessing capabilities in additional countries, encourage the creation of bilateral and multilateral assurances of nuclear fuel supply, and ensure that all supply mechanisms operate in strict accordance with the IAEA safeguards system." It would also authorize the President to negotiate mechanisms to assure fuel supply to countries who forego national nuclear fuel cycle capabilities.⁷⁸ While this bill supports the fuel bank initiative as a mechanism for supply assurance, it does not provide authorization for funding. The Senate Committee on Foreign Relations approved S. 1138 on June 27, 2007.

On June 18, 2007, the House passed H.R. 885, the International Nuclear Fuel for Peace and Nonproliferation Act of 2007, which would authorize \$50 million in FY2008 for establishing an IAEA fuel bank.⁷⁹ The bill, however, would place certain requirements on implementation: the fuel bank itself would have to be established on the territory of a non-nuclear weapon state under the oversight of the IAEA; any state receiving fuel from the bank must be in full compliance with its IAEA safeguards agreement and have an Additional Protocol in force; if the recipient state had previously been in noncompliance, the Board of Governors must determine that the state has taken all necessary actions to satisfy concerns of the IAEA Director General; the recipient agrees to use the fuel in accordance with its safeguards agreement; and the recipient does not operate uranium enrichment or spent fuel reprocessing facilities of any scale. An identical bill, S. 1700 was introduced in the Senate on June 26, 2007 and referred to the Senate Foreign Relations Committee. In addition, S. 970, the Iran Counterproliferation Act, contains the text of H.R. 885 in a subtitle, was introduced on March 22, 2007 and referred to the Senate Committee on Finance.

The House (H.R. 1585) and Senate versions (S. 1547) of the National Defense Authorization Act for Fiscal Year 2008 both authorize \$50 million to be appropriated to the Department of Energy for the "International Atomic Energy Agency Nuclear Fuel Bank." The conference report supports the establishment of a fuel bank and notes that "additional work will be required in order to provide appropriate guidance to the executive branch regarding criteria for access by foreign countries to any fuel

⁷⁷ For more detailed treatment of these questions see, *New Framework for the Utilization of Nuclear Energy in the 21st Century: Assurances of Supply and Nonproliferation*, IAEA Special Event, Speech by Laura Holgate, September 19, 2006, at [<http://www.nti.org>].

⁷⁸ See S.Rept. 110-151, Nuclear Safeguards and Supply Act of 2007.

⁷⁹ Introduced February 7, 2007, by Representative Lantos; reported by House Committee on Foreign Affairs June 18, 2007 (H.Rept. 110-196); passed House under suspension of the rules by voice vote.

bank established at the IAEA with materials or funds provided by the United States.”⁸⁰

Both the House (HR.2641) and Senate (S. 1751) Energy and Water Appropriations Acts recommended that funds be made available for an international nuclear fuel bank under the IAEA, and make available \$100 million and \$50 million respectively. The Consolidated Appropriations Act for FY2008, which became P.L. 110-161 on December 26, 2007, provided that \$50 million should be available until expended for “the contribution of the United States to create a low-enriched uranium stockpile for an International Nuclear Fuel Bank supply of nuclear fuel for peaceful means under the International Atomic Energy Agency.”

World Nuclear Association

In May 2006, the private-sector World Nuclear Association (WNA) Working Group on Security of the International Nuclear Fuel Cycle outlined proposals for assuring front-end and back-end nuclear fuel supplies.⁸¹ Like the Six Country Concept, the WNA proposal envisions a system of supply assurances that starts first with normal market procedures attempting to reestablish nuclear fuel supply after interruptions. Also similar to the Six-Party Proposal, a pre-established network of suppliers could be triggered through the IAEA if supply were interrupted for political reasons. If that network then failed, stocks held by national governments could be used.

The first tier of assurances, therefore, is through commercial suppliers. The second level of supply commitment would use a “standard backup supply clause” in enrichment contracts, supported by governments and the IAEA. “To ensure that no single enricher is unfairly burdened with the responsibility of providing backup supply, the other (remaining) enrichers would then supply the contracted enrichment in equal shares under terms agreed between the IAEA and the enrichers,” according to the proposal.

For fuel fabrication, a backup supply system would be more complicated, according to the WNA report. “Because fuel design is specific to each reactor design, an effective mechanism would require stockpiling of different fuel types/designs. The cost of such a mechanism could thus be substantial,” according to the report. However, WNA noted that unlike uranium enrichment technology, uranium fuel fabrication is not of proliferation concern.

The WNA report also noted the need for back-end nuclear fuel cycle supply assurances, to prevent a future scenario in which reprocessing technologies spread as nuclear power programs expand. The report recommends that a clear option to reprocess spent fuel at affordable prices is offered to states that do not have indigenous reprocessing programs. Such assurances would be part of a longer-term approach.

⁸⁰ H.Rept. 110-477 to accompany H.R. 1585.

⁸¹ WNA’s report is available at [<http://www.world-nuclear.org/reference/pdf/security.pdf>].

Other Proposals

Japan presented a “complementary proposal” to the Six Country Concept at the IAEA in September 2006. Japan’s concerns with the Six Country Concept centered on the implication that it would deny the right for states to use nuclear technology for commercial purposes and because it assured the supply only of LEU, rather than all front-end nuclear fuel cycle services. Japan proposed instead to create an “IAEA Standby Arrangements System” that would act as an early warning system to prevent a break in supply to recipients. With a list of supply capacities from each state updated annually and a virtual bank of front-end fuel cycle services (from natural uranium to fuel fabrication), the IAEA would facilitate supply to recipient states before supply was completely stopped. States determined by the IAEA Board of Governors to be in good non-proliferation standing by the IAEA could participate.

Germany proposed in May 2007 that a new enrichment facility be built and placed under IAEA ownership in a extraterritorial area.⁸² An independent management board or consortium would finance and run the plant on a commercial basis, but the IAEA would decide whether to supply enriched fuel according to nonproliferation criteria. Germany argues that this approach is advantageous since it does not prohibit uranium enrichment, but does provide a commercially viable, politically neutral option for fuel supply and could create competition on the world market by creating a new fuel service provider. With an economically viable option on neutral ground, it will be harder for states to justify starting their own enrichment program for commercial reasons.

The United Kingdom has proposed that enrichment bonds be created that would give advance assurance of export approvals for nuclear fuel to recipient states. The bonds would be an agreement between supplier state or states, the recipient state and the IAEA in which the supplier government would guarantee that, subject to the IAEA’s determination that the recipient was in good nonproliferation standing, national enrichment providers will be given the necessary export approvals to supply the recipient states. It is a transparent legal mechanism designed to give further credible assurance of supply with a ‘prior consent to export’ arrangement. The IAEA would make the final decision on whether conditions had been met to allow the export of LEU.⁸³

Global Nuclear Energy Partnership

In February 2006, U.S. Secretary of Energy Bodman announced the Global Nuclear Energy Partnership (GNEP), drawing together two of the Bush Administration’s policy goals: promotion of nuclear energy and nonproliferation. Recycling nuclear fuel to produce more energy and reduce waste, and encouraging global prosperity are a few of DOE’s stated aims for the program. GNEP builds on

⁸² “Safe Enrichment for All,” Handelsblatt newspaper, May 2, 2007, in English at [<https://www.diplo.de/diplo/en/Infoservice/Presse/Interview/2007/070502-Handelsblatt.html>].

⁸³ INFCIRC/707, June 4, 2007.

DOE's Advanced Fuel Cycle Initiative (AFCI), a program that began in 2003 to develop and demonstrate spent fuel reprocessing/recycling technology.

The domestic component of GNEP focuses on the future of nuclear energy in the United States: what kind of future reactors will be licensed, and how spent nuclear power reactor fuel will be handled. Existing commercial light water reactors are expected to continue as the predominant technology for at least the next two decades. Spent fuel from existing reactors would be stored or retrievably emplaced at the planned Yucca Mountain, NV, repository, awaiting future reprocessing and recycling.

Reprocessing facilities would use new technologies developed by AFCI to avoid separation of pure plutonium that could be used for weapons. However, there is some controversy over how proliferation-resistant such processes might be. High level waste from reprocessing (mostly fission products) would go to the Yucca Mountain repository, and the recycled plutonium and uranium would be fabricated into fuel for an Advanced Burner Reactor, a fast reactor to be developed by DOE's Generation IV Nuclear Energy Systems Initiative. In the longer term, plutonium and other transuranics in spent fuel would be fabricated into new fuel for future fast reactors. Eventually, that fuel would be continually recycled until all the transuranics are consumed, leaving the fission products to be disposed of in a geologic repository.

The international component of GNEP envisions a consortium of nations with advanced nuclear technology that would provide fuel services and reactors to countries that "refrain" from fuel cycle activities, such as enrichment and reprocessing. It is essentially a fuel leasing approach, wherein the supplier takes responsibility for the final disposition of the spent fuel. This could mean taking back the spent fuel, but might also mean, according to DOE, that the supplier "would retain the responsibility to ensure that the material is secured, safeguarded and disposed of in a manner that meets shared nonproliferation policies."⁸⁴ While this describes the responsibility of the supplier, the vagueness of the language suggests that any number of solutions, including on-site storage, could be the outcome.

GNEP envisions a system whereby supplier states take back spent fuel, but many nations lack the political will to do so. Skeptics have raised the question of whether the technology used in GNEP will be a net gain for nonproliferation efforts, since the United States does not reprocess or re-use plutonium now. In their view, the "proliferation-resistance" of technologies under consideration must be assessed against the status quo in the United States, which is disposal of sealed, intact fuel rods in a geologic repository.

Much of the AFCI's research is focusing on a separations technology called UREX+, in which uranium and other elements are chemically removed from dissolved spent fuel, leaving a mixture of plutonium and other highly radioactive elements. Proponents believe UREX+ is proliferation-resistant, because further purification would be required to make the plutonium useable for weapons and because its high radioactivity would make it difficult to divert or work with. In

⁸⁴ DOE Global Nuclear Energy Partnership home page, at [<http://www.gnep.energy.gov>].

contrast, conventional reprocessing using the PUREX process can produce weapons-useable plutonium.

However, critics see the potential nonproliferation benefits of UREX+ over PUREX as minimal. Richard Garwin suggested in testimony to Congress in 2006 that Urex+ fuel fails the proliferation-resistance test. Since it contains 90% plutonium, it could be far more attractive to divert than current spent fuel, which contains 1% plutonium. In other words, a terrorist would only have to reprocess 11 kg of Urex+ fuel to obtain roughly 10 kg of plutonium, in contrast to reprocessing 1,000 kg of highly radioactive spent fuel to get the same amount from light water reactor fuel.⁸⁵

Another nonproliferation-related concern about GNEP is how its implementation will affect global stockpiles of separated plutonium. Frank Von Hippel points to costly failed plutonium recycling programs in the U.K., Russia and Japan where separated plutonium stocks have accumulated to 250 tons, enough for 30,000 nuclear warheads. In Von Hippel's view, GNEP would exchange the safer on-site spent fuel storage at reactors for central storage of separated transuranics and high-level waste, cost ten times more, and increase the global plutonium stockpile.⁸⁶

A separate set of questions focuses on how effective GNEP will be in achieving its goals. As the only proposal currently that offers incentives for the back-end of the fuel cycle, it may hold more promise of attracting states to participate in the fuel supply assurances part of the framework. However, back-end fuel cycle assurances will require significant changes in policies and laws, as well as efforts to commercialize technologies. Further, it is far from clear that all suppliers will be able to offer the full range of fuel cycle assurances, raising the question of the relative competitiveness of suppliers. These critics do not argue that the overall vision of GNEP is misplaced, but instead are skeptical that its vision can be achieved, particularly in the timeframe proposed.

GNEP itself marks a departure from a U.S. policy of not encouraging the use of plutonium in civil nuclear fuel cycles. Supporters suggest that the U.S. policy developed in the late 1970s did not envision a recycling process that would not separate pure plutonium, and therefore question the underlying assumptions of that longstanding policy. Critics of GNEP have suggested that even though many nations did not agree with the United States in the 1970s on the dangers of having stockpiles of separated plutonium, the message that the United States conveyed was that reprocessing was unnecessary to reap the benefits of nuclear power and that GNEP conveys the opposite message now. Moreover, some critics point to the

⁸⁵ Richard Garwin, "R&D Priorities for GNEP," Testimony to House Science Committee, April 6, 2006.

⁸⁶ Frank von Hippel, "GNEP and the U.S. Spent Fuel Problem," Briefing for Congressional Staff, March 10, 2006, at [<http://www.princeton.edu/~globsec/publications/pdf/HouseBriefing10March06rev2.pdf>]; Frank von Hippel, "Managing Spent Fuel in the United States: The Illogic of Reprocessing," International Panel on Fissile Materials, January 2007, at [http://www.fissilematerials.org/ipfm/site_down/ipfmresearchreport03.pdf].

accumulation since the 1970s of separated plutonium as a particular threat, given the potential for terrorist interest in acquiring nuclear material.

An October 2007 study published by the National Academies of Science recommended that research and development activities for new reprocessing plants continue but be scaled back, with more time and peer review before commercial plants are built. It strongly criticized DOE's timeline for the program, saying that "achieving GNEP's goals are too early in development to justify DOE's accelerated schedule for construction of commercial facilities that would use these technologies."⁸⁷

The GNEP proposal has attracted some international interest, at least among potential supplier states. Officials from China, France, Japan, Russia, and the United States met in Washington, DC, on May 21, 2007, to discuss GNEP and its goals. According to a joint statement issued after the meeting, "The participants believe in order to implement the GNEP without prejudice to other corresponding initiatives, a number of near- and long-term technical challenges must be met. They include development of advanced, more proliferation resistant fuel cycle approaches and reactor technologies that will preserve existing international market regulations."

In a formal presentation of GNEP principles, made September 16, 2007 in Vienna, Austria, participation was opened to all nations on a voluntary basis that agree to internationally accepted standards for a safe, peaceful, and secure nuclear fuel cycle.⁸⁸ Sixteen countries joined the United States in signing the Statement of Principles for GNEP in September 2007, and Italy, Canada, and the Republic of Korea have joined the partnership since then.⁸⁹ The principles call for safe expansion of nuclear energy, enhanced nuclear safeguards, international supply frameworks, and development of fast reactors, "more proliferation resistant" nuclear power reactors and spent fuel recycling technologies in facilities that do not separate pure plutonium. They did not call upon states to renounce or refrain from indigenous development of enrichment or reprocessing technologies but emphasized the goal of creating "a viable alternative to acquisition of sensitive fuel cycle technologies." It further emphasized that participants would not be giving up any rights to benefit from peaceful nuclear energy.

It may be difficult for the United States and others to define which states are suppliers and which are recipients. Informally, U.S. policy currently recognizes 10 states as having enrichment capability — the five nuclear weapon states (U.S., U.K., France, China, Russia) plus Japan, Argentina, Brazil, the Netherlands, and Germany.

⁸⁷ "DOE's Spent Nuclear Fuel Reprocessing R&D Program Should Be Scaled Back; Boosted Efforts to Get New Nuclear Power Plants Online Needed," National Academies News Release, October 27, 2007, [<http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=11998>].

⁸⁸ "Remarks as Prepared for Delivery by U.S. Secretary of Energy Samuel W. Bodman," 2nd Global Nuclear Energy Partnership Ministerial Opening Session Vienna, Austria, September 16, 2007.

⁸⁹ [http://www.gnep.energy.gov/pdfs/gnepSOP_091607.pdf].

While Argentina has a plant (Pilcaniyeu) under safeguards, this plant has never operated commercially and it is doubtful that it will be cost-effective, since it uses outdated gaseous diffusion technology. Brazil's centrifuge enrichment plant at Resende is still in the early stages of commissioning and won't produce at a commercial scale for several years. States such as Australia, Canada, South Africa, and Ukraine have stated they would be interested in developing enrichment capability for export. On the reprocessing side, South Korea has expressed interest in becoming a GNEP supplier state through development of a pyroprocessing technique that does not separate plutonium from uranium. In the past, the United States for proliferation reasons has rejected requests from South Korea to reprocess U.S.-origin spent fuel.

Congress has itself raised concerns about GNEP. In the Consolidated Appropriations Act FY2008 (P.L. 110-161), Congress provided \$181 million out of \$395 million requested by the administration. Of this amount, \$151 million is for research, development, and design activities, with no funds for constructing facilities for technology demonstration or commercialization.⁹⁰ The additional \$30 million is for upgrades to existing facilities. The administration had proposed that technology demonstration facilities be built and begin operating in the period FY2008-FY2020.

In its press release, the House Energy and Water Appropriations Committee said that the budget cuts were made because "it is unnecessary to rush into a plan that continues to raise concerns among scientists and has only weak support from industry given that there are reasonable options available for short term storage of nuclear waste and that this project will cost tens of billions of dollars and last for decades."⁹¹ The Senate Report on Energy and Water Appropriations similarly cautioned that

the policy of reinitiating the recycling of spent nuclear fuel in the United States is a significant issue and one that has international implications.... The Committee believes the administration must come forward with greater scientific, technical, and policy information that examines more alternatives in the fuel cycle and recycling process. The administration is directed to limit the FY2008 work scope to research and development and technology demonstrations at existing facilities. No funds may be used beyond conceptual design of new facilities or the sodium cooled fast burner reactor.⁹²

Comparison of Proposals

Table 4 provides a comparison of the major proposals currently in circulation to restrict sensitive nuclear fuel technology development. The table is based on one

⁹⁰ See CRS Report RL34009, *Energy and Water Development: FY2008 Appropriations*, by Carl E. Behrens et al.

⁹¹ "Summary: 2008 Energy and Water Appropriations Full Committee Markup," [<http://appropriations.house.gov/pdf/EnergyandWater-FC.pdf>].

⁹² Nuclear Energy section, S.Rept. 110-127, Energy and Water Appropriations Bill, 2008.

created by Chaim Braun presented at the September 2006 IAEA conference on nuclear fuel supply assurances.⁹³

⁹³ The IAEA proposal is “Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report Submitted to the Director General of the International Atomic Energy Agency,” INFCIRC/640, International Atomic Energy Agency, February 22, 2006, p. 18. Available at [<http://www.iaea.org/Publications/Documents/Infcircs/2005/infcirc640.pdf>].

The Six-Country Concept is “Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel,” Proposal as sent to the IAEA from France, Germany, the Netherlands, Russia, Ireland, and the United States, May 31, 2006. Available at [http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2006/cn147_ConceptRA_NF.pdf].

Table 4. Comparison of Major Proposals on Nuclear Fuel Services and Supply Assurances

	IAEA/INFCIRC/640	Putin Initiative	GNEP	Six Country Concept	World Nuclear Association
Goals	Identify multilateral approaches across the fuel cycle; improve non-proliferation assurances without disrupting market mechanisms.	Establish international commercially operated nuclear fuel service centers in Russia, to include enrichment, education and training, and spent fuel management.	Enable expansion of nuclear power in the United States and around the world, promote nuclear nonproliferation goals, and help resolve nuclear waste disposal issues. Provide states with front-end and back-end services, to provide an alternative to the creation of national enrichment and reprocessing capabilities.	Create interim measures for front-end assurances.	Enhance supply security.
Target	Front-end and back-end services including uranium enrichment, fuel reprocessing, and disposal and storage of spent fuel. ^a	Supply of nuclear fuel and possibly other fuel cycle services.	Front- and back-end services. It could create new class of “reactor-only” states.	Supply of nuclear fuel.	Primarily fuel supply.

	IAEA/INFCIRC/640	Putin Initiative	GNEP	Six Country Concept	World Nuclear Association
Methods	Reinforce commercial contracts with transparent supplier arrangements with government backing. International supply guarantees backed by fuel reserves.	Commercial, long-term contracts; recipients will have limited control over joint ventures. IAEA will be involved. ^b	Use existing enrichment and reprocessing services; develop more proliferation-resistant technology. Fuel supplier will be responsible for spent fuel disposition.	Level I: Market Level II: Fuel assurance mechanism at IAEA Level III: Mutual commercial back-up arrangements Level IV: Enriched uranium reserves	Level I: Market meets demand Level II: Standard back-up supply clause in enrichment contracts, with IAEA assurances Level III: Gov't stocks of enriched uranium
IAEA Role	IAEA participates in administering supply guarantees, possibly as guarantor of service supplies with use of a fuel bank. Possible IAEA supervision of an international consortium for reprocessing services.	IAEA would ensure supply with fuel bank created by purchasing existing fuel stocks and placing them under its control (IAEA would receive new funding to do so).	IAEA would apply safeguards.	IAEA as broker. IAEA assesses status of safeguards agreements, safeguards implementation, safety, physical protection and whether a country is pursuing sensitive fuel cycle activities.	IAEA would approve "triggering" mechanism for supply back-up. IAEA could manage enriched uranium reserve.

	IAEA/INFCIRC/640	Putin Initiative	GNEP	Six Country Concept	World Nuclear Association
Eligibility	Recipient countries would renounce the construction and operation of sensitive fuel cycle facilities and accept safeguards of the highest current standards including comprehensive safeguards and the Additional Protocol.	Equal access, but prerequisite is compliance with the nonproliferation regime. Potential provider states could include Australia and Canada.	No requirements now (versus initial requirement for recipient states to forego enrichment and reprocessing).	IAEA-approved states that are in good NPT standing. States that develop national capabilities will not be eligible.	IAEA-approved states that meet all NPT obligations.
Role of Industry	Managing, operating centers.	Performing fuel services at designated center.	Performing fuel services, but not necessarily coordinated.	Perform enrichment contracts; identified need to address back-end of fuel cycle.	Perform enrichment contracts. No new capabilities required.
Potential Concerns	No mechanism specified for assessing state's nonproliferation record.	Incentives not specified, as well as compliance with nonproliferation regime. Unclear how commitments to forego sensitive fuel cycle activities will be incorporated into contracts.	Lack of political will to take back spent fuel. Concerns about gains for nonproliferation, if the United States was not reprocessing to begin with.	Incentives may be insufficient.	Incentives may be insufficient. How to determine price on enriched uranium reserves, if they are required.

a. INFCIRC/640, p. 103.

b. "Questions Abound on Proposals by Bush, Putin on Fuel Centers," *Nuclear Fuel*, March 13, 2006, vol. 31, no. 3.

Prospects for Implementing Fuel Assurance Mechanisms

Proposals to provide an international and institutional framework for peaceful nuclear activities have abounded since the 1940s, but few have been implemented. The U.S.-sponsored Baruch Plan introduced at the United Nations in 1946 recommended establishing an international agency with managerial control or ownership of all atomic energy activities. The International Atomic Energy Agency, established in 1957, emerged as a paler version of what was suggested in the Baruch Plan, but still retains authorities in its statute to store fissile material.

Concern about proliferation led to a flurry of proposals in the 1970s and 1980s as the United States and others convened groups to study the issues.⁹⁴ One idea studied in the mid-1970s was regional nuclear fuel cycle centers, focused on reprocessing technologies. Several factors contributed to its lack of success, despite support by the U.S. Congress: low uranium prices (making plutonium recovery relatively unattractive), a slump in the nuclear industry in the late 1970s and early 1980s, and U.S. opposition to reprocessing from the late 1970s. Member states of the IAEA also convened the International Fuel Cycle Evaluation project, which involved 60 countries and international organizations. INFCE working group reports suggested establishing a multi-tiered assurance of supply mechanism similar to the one proposed by the Six Country Concept in 2006. States also studied international plutonium storage in the late 1970s and early 1980s, but could not agree on how to define excess material or the requirements for releasing materials.

As in the past, the success of current proposals may depend on whether nuclear energy is truly revived not just in the United States, but globally. That revival will likely depend on significant support for nuclear energy in the form of policy, price supports, and incentives. Factors that may help improve the position of nuclear energy against alternative sources of electricity include higher prices for other sources (natural gas and coal through a carbon tax), improved reactor designs to reduce capital costs, regulatory improvements, and waste disposal solutions.

The willingness of fuel recipient states to participate in international enrichment centers rather than develop indigenous enrichment capabilities, and confidence in fuel supply assurance mechanisms such as an international fuel bank, will largely determine the success of the overall policy goal — to prevent further spread of enrichment and reprocessing technologies. So far, proposals addressing this challenge have originated in the supplier states, with many recipient states continuing to voice concern that their right to peaceful nuclear energy technology under the NPT is in jeopardy. Increasingly, however, participation is being presented as a market-based decision by a country not to, at least for the present, develop their own fuel enrichment program.

⁹⁴ For an analysis of these past proposals, see Lawrence Scheinman, “Equal Opportunity: Historical Challenges and Future Prospects of the Nuclear Fuel Cycle,” *Arms Control Today*, May 2007.

Another factor that will shape the success of these proposals is the possible addition of other incentives. Simply making nuclear energy cost-effective may not induce countries to forgo indigenous enrichment and reprocessing. Such decisions may require other incentives, perhaps even outside the nuclear realm, to make them palatable. The experience of Iran may be instructive here. Russia's offer to provide assured enrichment services on Russian soil has gone nowhere; instead, other, broader trade incentives may be necessary. While the case of Iran may illustrate the extreme end of the spectrum, in terms of a country determined to develop a capability for a weapons program, non-nuclear weapon states will clearly take notice of how a solution develops for Iran.

Issues for Congress

Congress would have a considerable role in at least four areas of oversight related to fuel cycle proposals. The first is providing funding and oversight of U.S. domestic programs related to expanding nuclear energy in the United States. Key among these programs are GNEP, the Advanced Fuel Cycle Initiative, other nuclear research and development programs, and federal incentives for building new commercial reactors.⁹⁵

The second area is policy direction and/or funding for international measures to assure supply. What guarantees should the United States insist on in exchange for helping provide fuel assurances? H.R. 885 contains nonproliferation requirements for states participating in an IAEA fuel bank, yet the NTI fuel bank and other proposals do not. Although the Six Country Concept contains an option for a fuel bank, it would not require participants to forswear enrichment and reprocessing.

A third set of policy issues may arise in the context of implementing the international component of GNEP. As referenced above, in the original policy documents, GNEP participant states would "agree to refrain from fuel cycle initiatives." However, in its most recent ministerial meeting, this language was no longer used and participation was opened to all. This is most likely meant to increase participation in the initiative by emphasizing that GNEP is not asking state to give up rights to peaceful nuclear technology.

Some observers believe that further restrictions on non-nuclear weapon states party to the NPT are untenable in the absence of substantial disarmament commitments by nuclear weapon states. In particular, a January 4, 2007, *Wall Street Journal* op-ed by George Schultz, Bill Perry, Henry Kissinger, and Sam Nunn, entitled "A World Free of Nuclear Weapons," noted that non-nuclear weapon states have grown increasingly skeptical of the sincerity of nuclear weapon states in this regard. Some observers have asserted that non-nuclear weapon states will not tolerate limits on NPT Article IV rights (right to pursue peaceful uses of nuclear energy) without progress under Article VI of the NPT (disarmament). Amending the NPT is seen by most observers as unattainable.

⁹⁵ See CRS Report RL33558, *Nuclear Energy Policy*, by Mark Holt.

The IAEA experts group report, INFCIRC/640, did point to the political usefulness of achieving a ban on producing fissile material for nuclear weapons (known as fissile material production cutoff treaty, or FMCT) to provide more balance between the obligations of nuclear and non-nuclear weapon states. Although the United States tabled a draft FMCT in May 2006 at the Conference on Disarmament in Geneva, negotiations await resolution of agenda issues that have plagued that body for over a decade. Further, some see the U.S. position that such a treaty is inherently unverifiable as a particular stumbling block.⁹⁶ Ultimately, any such treaty would require Senate advice and consent to ratification.

A fourth area in which Congress plays a key role would be in the approval of nuclear cooperation agreements. Two such agreements have been negotiated but not yet approved by Congress: one with India and one with Russia. The extent to which India is granted certain privileges (e.g., prior consent for reprocessing U.S.-origin material) may influence how Congress votes on the so-called Section 123 agreement (after the relevant portion of the U.S. Atomic Energy Act) with India. Such an agreement is required by the Atomic Energy Act before any significant nuclear equipment or material can be exported. The State Department released the details of the proposed agreement July 27, 2007, contending that it meets all statutory requirements.⁹⁷ Controversy in the Indian Parliament over the agreement has put it on hold as of mid-October 2007.

Presidents Bush and Putin announced that they had initialed the negotiated agreement in July 3, 2007.⁹⁸ Prior to 2006 when President Bush and Putin announced their intention to negotiate a 123 agreement, Russia's nuclear commerce with Iran presented the chief obstacle to such cooperation. Several factors may have contributed to U.S. officials de-linking peaceful nuclear cooperation with Russia from Russian behavior on Iran: a tougher line by Moscow since 2003 with respect to Iran and negotiation of spent fuel take back for the Russian-built Bushehr reactor as a condition of fuel supply; President Bush's embrace of nuclear power as an alternative to reliance on hydrocarbons and "dirty" energy sources; President Bush's proposals to multilateralize the nuclear fuel cycle and develop proliferation-resistant technologies through GNEP; and Russia's proposals to act as an international fuel center by storing and reprocessing spent fuel and enriching uranium for fresh fuel. Russia's nuclear expertise and infrastructure make it an important potential partner in expanding nuclear energy and developing future generations of proliferation-resistant reactors. A completed nuclear cooperation agreement with Russia could also pave the way for Russian reprocessing of U.S.-origin spent fuel from third countries (although Russia has not yet decided to do this). Congress has expressed its continued concern over Russia's nuclear and missile trade with Iran, and the Iran

⁹⁶ See CRS Report RS22474, *Banning Fissile Material Production for Nuclear Weapons: Prospects for a Treaty (FMCT)*, by Sharon Squassoni

⁹⁷ Daniel Horner, "India Agreement Complies With U.S. Law, State Department Official Says," *Nucleonics Week*, August 2, 2007, p. 1.

⁹⁸ Text of Declaration on Nuclear Energy and Nonproliferation Joint Actions, July 3, 2007, at [http://moscow.usembassy.gov/bilateral/joint_statement.php?record_id=64]. Once the agreement is submitted to Congress, the Congress will have 60 days to consider. If no objections are made, then the agreement becomes law.

Counter-Proliferation Act of 2007 (HR1400) which has been passed by the House, and S. 970 would prohibit any agreement with a country aiding Iran with its nuclear, advanced conventional or missile programs.

Figure 2: World Wide Nuclear Power Plants Operating, Under Construction, and Planned

