Nuclear Power Joint Fact-Finding

Executive Summary

June 2007

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About The Keystone Center

The Keystone Center is an independent, nonprofit, public policy and education organization with a distinguished history of convening diverse stakeholders, brokering productive information exchanges, building consensus and creating applied solutions to seemingly intractable policy problems. Through a method of "Dialogue by Design," stakeholders, technical information and high-quality social and political processes are joined in a way that produces smarter and more durable solutions. We focus on three substantive areas: energy, environment and public health. More information about The Keystone Center can be found at www.keystone.org.

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Photos courtesy of NEI and GE

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Endorsement

This report is designed to be an accurate portrayal of the NJFF group's discussions and joint findings. By endorsing this report, participants agree that they "generally support" the package of findings and the way the issues are described. To ensure an open and candid dialogue, participants presented their personal opinions in the Dialogue deliberations and not necessarily the official positions of their organizations. Therefore, the recommendations do not represent official government or organizational positions.

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Executive Summary

Nuclear technology is reemerging as a power generation option in the face of concerns about climate change, energy demand growth, and the relative cost of competing technologies. After more than a decade in which no new nuclear power plants were completed in the U.S., nuclear power is now the focus of considerable attention and debate. Nuclear power has long been controversial; consequently, the debate about its reemergence requires a fresh assessment of the facts about the technology, its economics and regulatory oversight, and the risks and benefits of its expansion. In the past year, the Keystone Center assembled a group of 27 individuals (see the Endorsement page for a list of Participants) with extensive experience and unique perspectives to develop a joint understanding of the "facts" and for an objective interpretation of the most credible information in areas where uncertainty persists. Participants represent diverse backgrounds and points of view—environmental and consumer advocates, the utility and nuclear power industry, non-governmental organizations, state regulators and former federal regulators, public policy analysts, and academics.

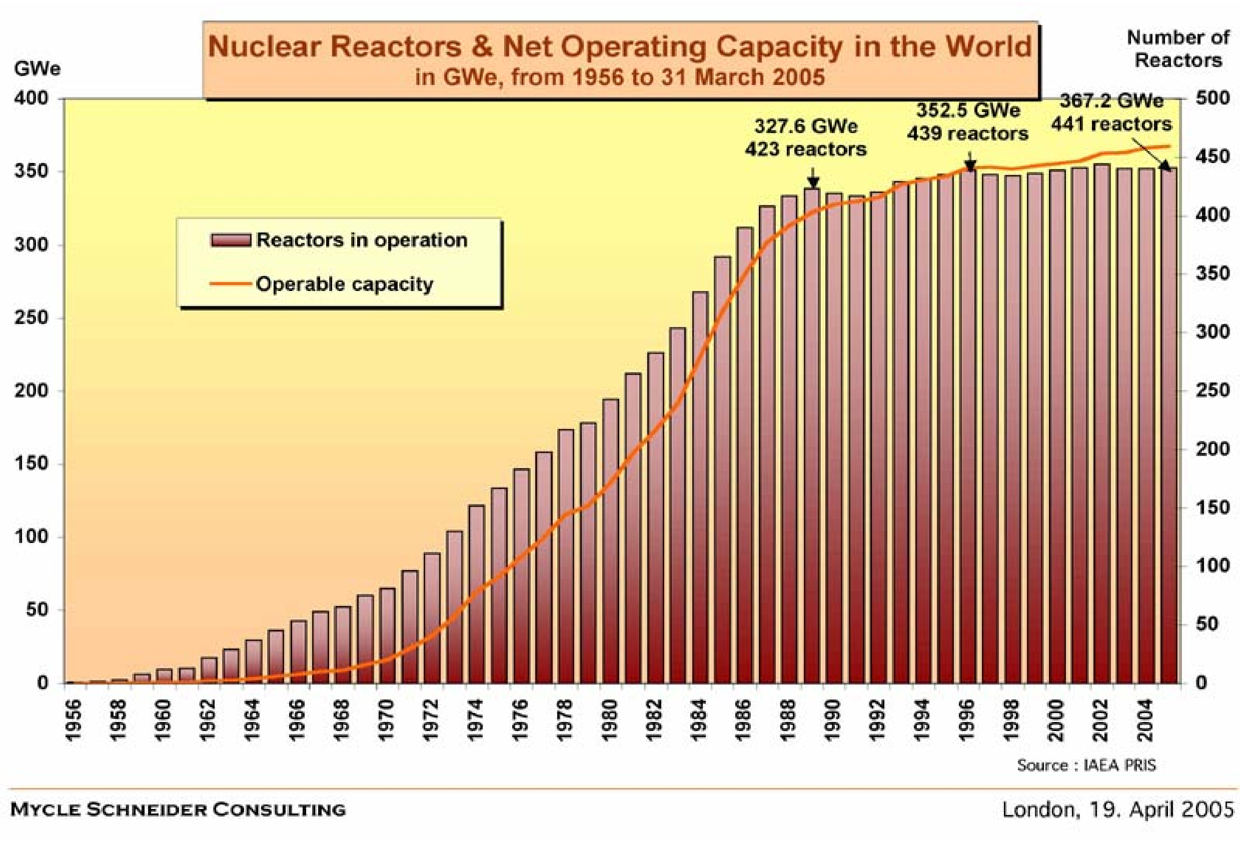
The participants consulted with a number of respected experts and conducted original analyses to answer questions they believe to be most important to an informed debate: Can we develop a reasonable range of expected costs to compare with other alternatives? How quickly can nuclear power be expanded to contribute to reducing worldwide greenhouse gas (GHG) emissions? What is the best way to manage nuclear waste? Can existing commercial nuclear facilities, as well as the next generation of nuclear reactors, be expected to operate safely and with adequate security safeguards in place? Should additional institutions or safeguards be put in place to prevent the proliferation of nuclear weapons derived from commercial fuel cycle activities?

We trust that the research, expertise, and deliberations of this broad range of individuals lend strong credibility to the findings, which are intended to lay the foundation for continued discussions of the role of nuclear power in the U.S. and abroad. We expect, nonetheless, that readers will draw their own conclusions, since many of the findings are best efforts to interpret uncertainties.

Nuclear Power and Climate Change Mitigation

Members of the Nuclear Power Joint Fact Finding (NJFF) reached no consensus about the likely rate of expansion for nuclear power in the world or in the U.S. over the next 50 years. Some group members thought it was unlikely that overall nuclear capacity would expand appreciably above its current levels and could decline; others thought that the nuclear industry could expand rapidly enough to fill a substantial portion of a carbon-stabilization "wedge" during the next 50 years.

To maintain the low-carbon benefits of the current 435 nuclear plants (370 GWe) around the world that will be retired over the next 50 years and to expand nuclear power's share of electricity generation would require an ambitious nuclear reactor building program. We looked at the number of nuclear power plants that would be required to displace 1 gigatonne of carbon annually from an equivalent amount of generation by new, efficient coal plants by the end of 50 years (a "carbon stabilization wedge.")[1]



Source: Mycle Schneider Consulting.

[1]Pacala and Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science*, 13 August 2004, Vol. 305, No. 5686. pp 968-972.

The NJFF participants agree that to build enough nuclear capacity to achieve the carbon reductions of a Pacala/Socolow wedge (1 GtC/year or 700 net GWe nuclear power; 1,070 total GWe) would require the industry to return immediately to the most rapid period of growth experienced in the past (1981-90) and sustain this rate of growth for 50 years.

This projection is more optimistic than indicated by the current announcements of proposed plant construction reported by the World Nuclear Association, is higher than the average historical growth rate during the industry's first 40 years, and represents more rapid industry growth than forecast by the Energy Information Administration for the U.S for the next 30 years.

We know that in a carbon-constrained world, in which either a substantial greenhouse gas (GHG) tax or cap and trade program is implemented, the relative economics of nuclear power (as compared to fossil-fueled power) will improve.

Climate policies enhance the position of all low-GHG sources of power, including: renewables, coal with carbon capture and sequestration, and energy efficiency investments. A broadly applied GHG tax or cap and trade program would create GHG saving alternatives in all sectors. The more stringent the climate policy (the greater the reduction target or the higher the carbon tax), the greater the relative economic advantage of nuclear and other low-GHG technologies.

Economics of Nuclear Power

The NJFF participants reviewed a number of studies that evaluated the life-cycle levelized cost of future nuclear power.[2] *We also relied on our own spreadsheet model to analyze the sensitivity of costs and price to certain factors. We found that a reasonable range for the expected levelized cost of nuclear power is between 8 and 11 cents per kilowatt-hour (kWh) delivered to the grid.*

We agreed that the most recent construction experience is the best indicator of future costs. We considered a likely range of assumptions on the critical cost factors, such as escalation of material costs, length of construction period, and capacity factor. While this value is significantly higher than many current vendor or government estimates, that is because our estimates are based on recent escalation in construction and raw material costs, which can be compounded in the future by tightness in the supply chain (availability of large forgings, skilled contractors and crews, etc.). Factors other than cost can have an acute impact on the outlook of investors, CEOs, and regulators about the potential risks and benefits of a nuclear investment, including the market structure, certainty of regulatory oversight, public perception, and the disposition of nuclear waste.

Summary of Levelized Cost (Cents/kWh)

Cost Category	Low Case	High Case
Capital Costs	4.6	6.2
Fuel	1.3	1.7
Fixed O&M	1.9	2.7
Variable O&M	0.5	0.5
Total (Levelized Cents/kWh)	8.3	11.1

[2]Levelized life-cycle cost is the total cost of a project from construction to retirement and decommissioning, expressed in present value and then spread evenly over the useful output (kWh) of the product.

The NJFF group concludes that while some companies have announced their intentions to build "merchant" nuclear power plants, it will likely be easier to finance nuclear power in states where the costs are included in the rate base with a regulated return on equity.

We also recognize that developers may face regulatory hurdles in cost-of-service states, which may make it difficult to build plants in some states. The power plant cost overruns of the 1970s and 1980s have led to a number of changes in the traditional cost-of-service regulatory framework that creates a more rigorous environment in which to consider new capital-intensive generation investments.

Safety and Security

According to the U.S. Nuclear Regulatory Commission (NRC) assessment, U.S. nuclear power plants meet the NRC's safety goal. Some NJFF participants agree with this assessment. Others believe that the methodology used cannot adequately demonstrate that the NRC safety goal is being met.

The method that the NRC currently uses to assess the safety of a nuclear power plant is a quantitative risk assessment known as Probabilistic Risk Assessment (PRA). Variations in the quality of data, models, and assumptions used at each power plant, and different perceptions about the capacity to quantify low-probability catastrophic accidents led to disagreement about the adequacy and reliability of the NRC's assessment.

On balance, commercial nuclear power plants in the U.S. are safer today than they were before the 1979 accident at Three Mile Island.

The NJFF participants reviewed a number of factors, including improvements in plant equipment and human performance, organizational and risk insights gained through experience, the implications of aging materials and components, and institutional changes in safety oversight. All participants agree that a strong safety culture is necessary to ensure the protection of public health and safety; not everyone agreed that the safety culture at all U.S. power plants is strong enough (e.g., the Davis-Besse event). The participants also did not agree on whether or not the NRC Commissioners have been consistently effective in ensuring the safe operation of current nuclear power plants.

There is agreement that, while plants have gotten safer since the Three Mile Island accident, public concern over plant security is greater today than it was before September 11, 2001. There is not agreement on whether it has been demonstrated that the security systems and procedures to protect existing reactors are sufficiently robust. In the current classification environment, it is difficult for outside entities lacking security clearances to adequately assess security measures, as well as their implementation and oversight.

NJFF participants, some with security clearances who have analyzed the Design Basis Threat (DBT) and current security measures, disagree about whether the DBT and its oversight are adequate. The DBT profiles the type, composition, and capabilities of an adversary as a basis for designing safeguards and security systems to protect against acts of radiological sabotage and to prevent the theft of special nuclear material. The details of the post-September 11th DBT are no longer available to the public; and there remains debate, even among some NRC Commissioners and staff, about how prescriptive a DBT should be.

The public ought to be able to trust both the nuclear industry and the federal agency conducting its security oversight. Transparency is a key cornerstone for public trust-building. However, when it comes to the security of nuclear power plants, full disclosure may be counter-productive.

There is agreement that the details of security measures (e.g., the number and location of guards, barriers, and alarms) should be kept classified to ensure their effectiveness. Debate continues about how much information should be made public on security measures and on related oversight by the NRC in order to instill public confidence.

Over the next two or three decades, the safety and security of the U.S. nuclear industry will largely be determined by the safety and security of existing reactors. Principal concerns for the U.S. power plants will continue to be those related to aging equipment and materials, as well as potential terrorist threats.

New reactors are expected to include advanced features that enhance both safety and security; however, existing reactors should be the focus of primary attention for improved safety and security, as they are likely to receive license extensions and for the next 30 years will outnumber new reactors.

On balance, this group has concerns about nuclear plant expansion in certain other countries that currently have significant weaknesses in legal structure (rule of law); construction practice; operating, safety, and security cultures; and regulatory oversight.

A reliable safety culture is critical to any safe commercial nuclear program, but the current safety culture varies greatly among countries. Systematic assessments of non-U.S. safety and security preparedness proved nearly impossible for the NJFF group, as there are no international standards that require countries with commercial nuclear power to meet minimum safety security standards, and current practices are generally kept classified.

Substantial changes have been made to the nuclear power plant licensing process in the last 15 years. These include moving consideration of public input toward the front of the process before significant capital expenditures are made. They also include new procedural modifications in such areas as raising contentions, cross-examination and discovery. Some members of the NJFF believe that the procedural modifications limit effective public involvement and could have a deleterious effect on safety and security.

Public involvement in the licensing process permits the opportunity to raise issues that will improve the safety of nuclear power plants and analysis of other alternatives. It also enhances the levels of transparency and trust in governmental decision-making. The NRC licensing process is the only federal forum for raising these issues, but the NJFF participants could not agree on whether or not the changes in the public participation process have overly constrained public involvement.

Waste and Reprocessing

There is consensus among the NJFF group that spent nuclear fuel must ultimately be placed in long-term disposal facilities, and that the best disposal option is a deep underground geologic repository. A consensus also exists regarding the suitable environments for geologic repositories. However, thus far, nations have yet to actually site and complete these repositories.

The NJFF participants agreed with the technical group convened by the International Atomic Energy Agency as to the desirable characteristics of a nuclear waste repository: geologic stability, low groundwater content and flow, stable geochemical or hydrochemical conditions, and good engineering properties that allow for ease of construction. Suitable geological environments for disposal exist throughout the world, including in the U.S., but each provides different combinations of desirable characteristics that must be judged on a site-specific basis.

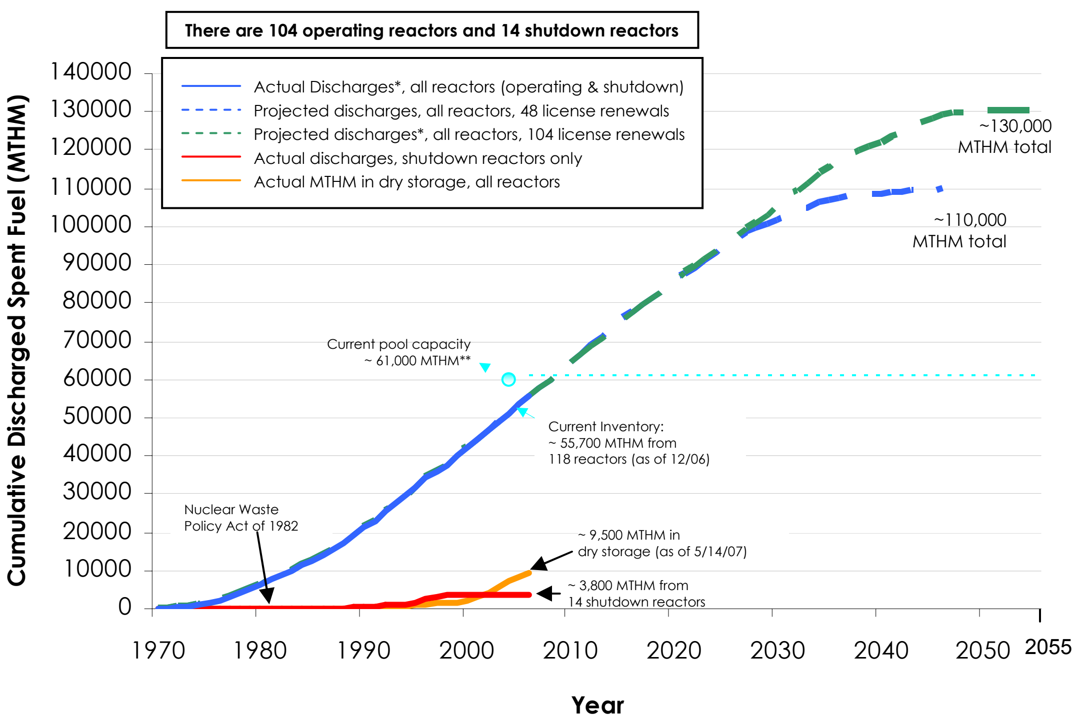
The NJFF group observes that the Yucca Mountain project has repeatedly failed to meet its own schedule. There is little confidence that currently established DOE schedules will be met. Projected delays in the commissioning of a repository mean added liability for the federal government, open-ended obligations on the part of nuclear plant owners to manage spent fuel, and additional physical and financial requirements for interim storage. Given this experience, the search for a second site or an alternative site would benefit from a different approach.

The availability of a repository in the U.S. is currently a decade behind schedule due to past and ongoing political, technical, and legal challenges. If the Yucca Mountain license application is submitted to NRC in June 2008 as currently projected, the most optimistic date for first emplacement of waste will be 2017, but more likely it will be beyond 2020. The EPA-proposed dose limit standard, which is a critical component of the licensing process, was rejected by the DC Court of Appeals in 2004. A revised final standard, which may also face legal challenges, has not been issued. To get an NRC license, DOE will have to demonstrate convincingly that it will meet the final EPA standard. The cost of completing and operating Yucca Mountain consequently remains uncertain, and continued delays, changes in design, and changes in requirements for spent fuel transportation add to the uncertainty. The NJFF participants considered but did not analyze alternative decision-making processes to those used by DOE in consideration of Yucca Mountain.

Yucca Mountain has a statutory capacity limit that is less than the amount of spent fuel expected to be produced by currently operating reactors over their licensed lifetimes. Any net expansion of U.S. nuclear power generation would require significantly greater repository capacity than currently established by law for Yucca Mountain.

The statutory capacity of Yucca Mountain is 70,000 metric tons. Congress may increase the capacity or may authorize DOE to begin the search for a second repository. Under the National Waste Policy Act, DOE must submit to Congress a proposal to do so no later than 2010. Some states legally restrict the expansion of nuclear power until a long-term solution for waste management is in place.

Historical and Projected Commercial Spent Nuclear Fuel Discharges as of May 14, 2007



Sources: * Based on actual discharge data as reported on RW-859's through 12/31/02, and projected discharges, in this case, based on 104 license renewals.
** Represents the aggregate industry pool capacity based on pool capacities provided in 2002 RW-859 (less FCR) and supplemented by utility storage plans. However, the industry is not one big pool and storage situations at individual sites differ based on pool capacities versus discharges into specific pools.

With regard to older spent fuel that must be stored on an interim basis until an operating repository is available, the NJFF participants believe that this spent fuel can be stored safely and securely in either spent fuel pools or dry casks, on-site. The NJFF group also agrees that centralized interim storage is a reasonable alternative for managing waste from decommissioned plant sites and could become cost-effective for operating reactors in the future.

Three options exist for spent fuel storage: on-site fuel pools, on-site dry cask storage systems, and centralized storage in dry casks. Although pool storage capacity is constrained at some sites, the dry storage option generally is not; however, dry cask storage incurs additional costs. Centralized dry cask storage for spent fuel currently at decommissioned plant sites may make sense, because it would allow more efficient management and oversight of the spent fuel and allow reuse of land at decommissioned plants.

There is wide agreement among the NJFF group participants that transport of spent fuel and other high-level radioactive waste is highly regulated, and that it has been safely shipped in the past. Security requirements during transport have been enhanced in response to 9/11; however, transport security will require continued vigilance. Transport of spent fuel to any repository will take many years to complete, and will require ongoing regulatory oversight.

If Yucca Mountain is licensed or centralized interim storage is permitted, the spent fuel must be transported. Total shipments of waste are expected to take 24 years to complete. Since 1965 there have been more than 2,700 relatively small shipments of spent nuclear fuel in the U.S., covering more than 1.6 million miles. Although there have been accidents in that time, there were no injuries, no breach of the containers, and no release of radioactivity. Under the NWPA disposal program, DOE and commercial carriers will plan and conduct spent fuel shipments under extensive federal regulations for rail, highway, and water modes. Interstate transportation protocols have been in place for several decades.

No commercial reprocessing of nuclear fuel is currently undertaken in the U.S. The NJFF group agrees that while reprocessing of commercial spent fuel has been pursued for several decades in Europe, overall fuel cycle economics have not supported a change in the U.S. from a "once-through" fuel cycle. Furthermore, the long-term availability of uranium at reasonable cost suggests that reprocessing of spent fuel will not be cost-effective in the foreseeable future. A closed fuel cycle with any type of separations program will still require a geologic repository for long-term management of waste streams.

Reprocessing as currently practiced is several times more expensive than a once-through fuel cycle system. Uranium prices have increased dramatically over the past 10 years, but this has not changed our fundamental conclusion that reprocessing is uneconomic. While reprocessing decreases the volume of high-level waste, a geologic repository is still needed. In addition, the volume of low- and intermediate-level wastes substantially increases with reprocessing, and these radioactive waste streams need to be disposed of in facilities that require siting and long-term management. The Global Nuclear Energy Partnership (GNEP), which includes an advanced reprocessing component, was proposed in 2006 to help expand nuclear power in the U.S. and abroad by, among other things, reducing the number of geologic repositories that would eventually be needed to sequester nuclear waste. But from a waste management perspective, there are many potential problems with the GNEP concept, including cost, technology choice, and waste streams.

Proliferation

Expansion of nuclear power in ways that substantially increase the likelihood of the spread of nuclear weapons is not acceptable.

Proliferation of nuclear weapons can occur without an expansion of the commercial nuclear power industry, but the challenges increase as the industry grows. In particular, if growth in commercial nuclear power plants also results in the construction of fuel cycle facilities in countries that do not now possess nuclear weapons, the risk of proliferation will increase. Proliferation can occur by the actions of either national governments (state actors) or non-state, possibly terrorist organizations. Weapons-grade materials can be obtained from states or non-state actors, or they can be developed by the non-nuclear weapons states using either dedicated weapons facilities or IAEA-safeguarded civilian nuclear fuel cycle facilities.

The NJFF participants agree that there are critical shortcomings in the current IAEA safeguards and that the international community has not demonstrated that the enforcement mechanisms are effective.

Today there is a collection of treaties, agreements, and commitments that are applied to peaceful uses of nuclear energy; they are designed to reduce the likelihood that special fissionable and other materials, services, equipment, facilities, and information will be used for military purposes. The International Atomic Energy Agency (IAEA) is the institution responsible for safeguarding civil nuclear activities in non-weapons states. The IAEA safeguards are currently insufficient to provide timely detection when weapon quantities of HEU and plutonium are diverted. This is because the time required to convert different forms of nuclear material to the metallic components of a nuclear explosive device are short compared to the IAEA timeliness detection goals used to define the frequency of inspections. Also, significant quantities (SQ) of nuclear material, defined by IAEA for the purpose of monitoring inventories and detecting diversion or theft of materials, are significantly greater than the amount of material needed to make a nuclear weapon without detection.

The NJFF participants agree that a principal proliferation concern is the diversion or theft of material from bulk fuel handling facilities (e.g., reprocessing, enrichment, mixed-oxide fuel fabrication, and plutonium storage facilities) to develop weapons capability.

While efforts have been made in the past to preclude non-weapons states from acquiring reprocessing or enrichment technologies, they have not always been successful. Non-weapons states can operate civilian fuel cycle facilities, particularly enrichment plants, mixed-oxide fuel fabrication facilities, and reprocessing facilities. It is relatively simple to use these technologies to produce weapons-grade material.

Growing stocks of civilian separated plutonium (250 tons and growing at a rate of 10 tons/yr) pose a significant proliferation risk and require extraordinary protection and international attention. Diversion or theft of these stocks represents a risk of weapons development by sub-national terrorist organizations. Levels of physical protection and risk vary widely from country to country.

While a number of countries have reprocessed spent fuel, few have used the separated plutonium as fuel in light-water reactors, mainly because such mixed-oxide fuel is currently more expensive than using enriched natural uranium. There are three options for dealing with the risk posed by civilian separated plutonium. First, it can be stored indefinitely. Second, the plutonium can be fabricated into mixed-oxide fuel, burned in reactors, and converted to spent fuel. Finally, the plutonium can be "diluted" by adding it to materials that would allow for permanent underground storage with low risk of criticality.

While the NJFF agrees with several premises of the GNEP, the program is not a strategy for resolving either the radioactive waste problem or the weapons proliferation problem. The NJFF group agrees with the following proliferation concerns that GNEP attempts to address:

- All grades of plutonium, regardless of the source, could be used to make nuclear explosives and must be controlled.
- Reprocessing poses a problem in non-weapons states. Widespread use of mixed-oxide fuel by both weapons states and non-weapons states is similarly troublesome.
- Even in the weapons states, plutonium must be protected, and one should not increase stocks of plutonium in separated or easily separated forms such as mixed-oxide fuel.

Estimated Quantities of Civilian Separated Plutonium by Country

Country	Civilian Pu Stock at End of 2005 (Tonnes)
Belgium	3.3 (plus 0.4 in France)
France	81.0 (30 foreign-owned)
Germany	12.5 (plus 15 in France and UK)
India	5.4
Japan	5.9 (plus 38 in France and UK)
Russia	41.0
Switzerland	<2.0 (in France and UK)
UK	105.0 (27 foreign owned plus 0.9 abroad)
Total	**250.0**

The NJFF participants believe that critical elements of the GNEP are unlikely to succeed because:

- GNEP requires the deployment of commercial-scale reprocessing plants, and a large fraction of the U.S. and global commercial reactor fleets would have to be fast reactors.
- To date, deployment of commercial reprocessing plants has proven uneconomical.
- Fast reactors have proven to be uneconomical and less reliable than conventional light-water reactors.

Although it is not its aim, the GNEP program could encourage the development of hot cells and reprocessing R&D centers in non-weapons states, as well as the training of cadres of experts in plutonium chemistry and metallurgy, all of which pose a grave proliferation risk.

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