NUCLEAR FUEL REPROCESSING

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE

HOUSE OF REPRESENTATIVES

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NUCLEAR FUEL REPROCESSING

THURSDAY, JUNE 16, 2005

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:05 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Judy Biggert [Chairwoman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Nuclear Fuel Reprocessing

Thursday, June 16, 2005
10:00 a.m. - 12:00 p.m.
2318 Rayburn House Office Building (WEBCAST)

Witness List

Mr. Robert Shane Johnson
Acting Director of the Office of Nuclear Energy, Science and Technology; and the Deputy Director for Technology at the Department of Energy

Dr. Phillip J. Finck
Deputy Associate Laboratory Director, Applied Science and Technology and National Security at Argonne National Laboratory

Dr. Roger Hagengruber
Director of the Office for Policy, Security and Technology; Director of the Institute for Public Policy; and professor of political science at University of New Mexico

Mr. Matthew Bunn
Senior Research Associate in the Project on Managing the Atom at Harvard University's John F. Kennedy School of Government

HEARING CHARTER

SUBCOMMITTEE ON ENERGY
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Nuclear Fuel Reprocessing

THURSDAY, JUNE 16, 2005
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

On Thursday, June 16, the Energy Subcommittee of the House Committee on Science will hold a hearing to examine the status of nuclear fuel reprocessing technologies in the United States.

Report language accompanying the House-passed H.R. 2419, the *Energy and Water Development Appropriations Act for Fiscal Year 2006,* directs the Department of Energy (DOE) to accelerate efforts to develop reprocessing technologies and to recommend a specific technology by September 2007.

The hearing will examine the status of reprocessing technologies and the impact reprocessing would have on energy efficiency, nuclear waste management and weapons proliferation.

2. Witnesses

Mr. Robert Shane Johnson is the Acting Director of the Office of Nuclear Energy, Science and Technology and the Deputy Director for Technology at the Department of Energy.

Dr. Phillip J. Finck is the Deputy Associate Laboratory Director, Applied Science and Technology and National Security at Argonne National Laboratory.

Dr. Roger Hagengruber serves at the University of New Mexico as Director of the Office for Policy, Security and Technology; Director of the Institute for Public Policy; and Professor of Political Science. He also chairs the Nuclear Energy Study Group of the American Physical Society, which issued a May 2005 report, *Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk.*

Mr. Matthew Bunn is a Senior Research Associate in the Project on Managing the Atom at Harvard University's John F. Kennedy School of Government.

3. Overarching Questions

- What are the advantages and disadvantages of nuclear reprocessing in terms of efficiency of fuel use, disposal of nuclear waste, and proliferation of nuclear weapons?
- What is the current state of reprocessing technologies? What criteria should be used to choose a technology? What do we still need to know to make this decision? Would choosing a reprocessing technology in 2007 limit future choices regarding other nuclear technologies, such as reactor designs?

4. Brief Overview

- Nuclear reactors generate about 20 percent of the electricity used in the U.S. No new nuclear plants have been ordered in the U.S. since 1973, but there is renewed interest in nuclear energy both because it could reduce U.S. dependence on foreign oil and because it produces no greenhouse gas emissions.
- One of the barriers to increased use of nuclear energy is concern about nuclear waste. Every nuclear power reactor produces approximately 20 tons of highly radioactive nuclear waste every year. Today, that waste is stored onsite at the nuclear reactors in water-filled cooling pools, or at some sites, after sufficient cooling, in dry casks above ground. About 50,000 metric tons of commercial spent fuel is being stored at 73 sites in 33 states. A recent report issued by the National Academy of Sciences concluded that this stored waste could be vulnerable to terrorist attacks.

- Under the current plan for long-term disposal of nuclear waste, the waste from around the country would be moved to a permanent repository at Yucca Mountain in Nevada, which is now scheduled to open around 2012. Yucca continues to be a subject of controversy. But even if it opened and functioned as planned, it would have only enough space to store the nuclear waste the U.S. is expected to generate by about 2010.
- Consequently, there is growing interest in finding ways to reduce the quantity of nuclear waste. A number of other nations, most notably France and Japan, "reprocess" their nuclear waste. Reprocessing involves separating out the various components of nuclear waste so that a portion of the waste can be recycled and used again as nuclear fuel (instead of disposing of all of it). In addition to reducing the quantity of nuclear waste, reprocessing allows nuclear fuel to be used more efficiently. With reprocessing, the same amount of nuclear fuel can generate more electricity because some components of it can be used as fuel more than once.
- The greatest drawback of reprocessing is that current reprocessing technologies produce weapons-grade plutonium (which is one of the components of the spent fuel). Any activity that increases the availability of plutonium increases the risk of nuclear weapons proliferation.
- Because of proliferation concerns, the U.S. decided in the 1970s not to engage in reprocessing. (The policy decision was reversed the following decade, but the U.S. still did not move toward reprocessing.) But the Department of Energy (DOE) has continued to fund research and development (R&D) on nuclear reprocessing technologies, including new technologies that their proponents claim would reduce the risk of proliferation from reprocessing.
- The report accompanying H.R. 2419, the *Energy and Water Development Appropriations Act for Fiscal Year 2006,* which the House passed in May, directed DOE to focus research in its Advanced Fuel Cycle Initiative program on improving nuclear reprocessing technologies. The report went on to state, "The Department shall accelerate this research in order to make a specific technology recommendation, not later than the end of fiscal year 2007, to the President and Congress on a particular reprocessing technology that should be implemented in the United States. In addition, the Department shall prepare an integrated spent fuel recycling plan for implementation beginning in fiscal year 2007, including recommendation of an advanced reprocessing technology and a competitive process to select one or more sites to develop integrated spent fuel recycling facilities."
- During Floor debate on H.R. 2419, the House defeated an amendment that would have cut funding for research on reprocessing. In arguing for the amendment, its sponsor, Mr. Markey, explicitly raised the risks of weapons proliferation. Specifically, the amendment would have cut funding for reprocessing activities and interim storage programs by $15.5 million and shifted the funds to energy efficiency activities, effectively repudiating the report language. The amendment was defeated by a vote of 110–312.
- But nuclear reprocessing remains controversial, even within the scientific community. In May 2005, the American Physical Society (APS) Panel on Public Affairs, issued a report, *Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk.* APS, which is the leading organization of the Nation's physicists, is on record as strongly supporting nuclear power. But the APS report takes the opposite tack of the Appropriations report, stating, "There is no urgent need for the U.S. to initiate reprocessing or to develop additional national repositories. DOE programs should be aligned accordingly: shift the Advanced Fuel Cycle Initiative R&D away from an objective of laying the basis for a near-term reprocessing decision; increase support for proliferation-resistance R&D and technical support for institutional measures for the entire fuel cycle."
- Technological as well as policy questions remain regarding reprocessing. It is not clear whether the new reprocessing technologies that DOE is funding will be developed sufficiently by 2007 to allow the U.S. to select a technology to pursue. There is also debate about the extent to which new technologies can truly reduce the risks of proliferation.
- It is also unclear how selecting a reprocessing technology might relate to other pending technology decisions regarding nuclear energy. For example, the U.S. is in the midst of developing new designs for nuclear reactors under DOE's Generation IV program. Some of the potential new reactors would

produce types of nuclear waste that could not be reprocessed using some of the technologies now being developed with DOE funding.

- Finally, the economics of nuclear reprocessing are unclear. (The Committee intends to examine the economic questions in a later hearing.) The U.S. nuclear industry has not been interested in moving to reprocessing because today it is cheaper to mine uranium and turn it into fresh fuel (through "uranium enrichment") than it is to reprocess and recycle spent fuel.

5. Background

Current U.S. Practice: The open fuel cycle

Current U.S. nuclear technology uses what is called an "open fuel cycle," also known as a "once-through cycle" because the nuclear fuel only goes through the reactor one time before disposal, leaving most of the energy content of the uranium ore unused. In an open cycle, the uranium is mined and processed, enriched, and packaged into fuel rods, which are then loaded into the reactor. In the reactor, some of the uranium atoms in the fuel undergo fission, or splitting, releasing energy in the form of heat, which in turn is used to generate electricity. Once the fission efficiency of the uranium fuel drops below a certain level, the fuel rods are removed from the reactor as spent fuel. Spent fuel contains 95 percent uranium by weight, one percent plutonium, with the remaining four percent consisting of fission products (Strontium, Cesium, Iodine, Technetium) and a class of elements known as actinides (Neptunium, Americium and Curium).

Actinides are a class of radioactive metals that are major contributors to the long-term radioactivity of nuclear waste. The fission products and actinides have half-lives[1] ranging from a few days to millions of years. The ongoing radioactivity of the spent fuel means that it still generates a lot of heat, so after removal, the spent fuel rods are cooled in deep, water-filled pools. After sufficient cooling, the fuel rods may be transferred to dry cask storage pending ultimate disposal at a geologic waste repository such as Yucca Mountain. Often they are just left in the cooling pools while awaiting disposal.

A recent National Academy of Sciences study examined the vulnerability of interim spent fuel storage to terrorist attack. After a dispute with the Nuclear Regulatory Commission, the Academy released a declassified version of the study in April, titled *Safety and Security of Commercial Spent Nuclear Fuel Storage.*[2] That report concluded that the pools, under certain conditions, could be vulnerable to attack, resulting in a large release of radioactivity, and recommended steps to reduce the risk of such an incident. Dry cask storage has inherent security advantages, according to the study, but can be used only after the fuel has cooled for at least five years in a water-filled pool.

If the licenses for most currently operational nuclear power plants are extended to allow a 60-year operational lifetime as anticipated, the U.S. will need to make a choice: increase the statutory storage capacity of Yucca, build a second repository, close the fuel cycle, or change the Nuclear Waste Policy Act to allow indefinite above-ground dry storage until another solution is found. Some suggest that such a decision is a necessary prerequisite to any expansion of the nuclear industry in this country, in large part because the public needs to be convinced that the U.S. has a long-term strategy for waste disposal. In addition, by law, the Nuclear Regulatory Commission must make a "waste confidence determination"—that the waste created can be safely disposed of—in order to continue issuing facility licenses.

Closing the fuel cycle: Reprocessing and Recycling

The "closed" fuel cycle requires the same mining, processing and fuel fabrication as the open cycle, prior to initial loading of the fresh fuel rods into the reactor. However, in the closed cycle, the cooled spent fuel is reprocessed, or separated into its individual components. In this approach, some components of the spent fuel can be used to fabricate new fuel for the reactor. The unusable waste is either safely encased and disposed of as is (which means it is still very hot and radioactive), or "burned" in a different type of reactor to reduce the heat and radioactivity and then disposed of. In theory, the fuel can go around this cycle many times until most of

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[1] The "half-life" of a radioactive substance is the period of time required for one-half of a given quantity of that substance (e.g., plutonium) to decay either to another isotope of the same element, or to another element altogether. The substances with shorter half-lives tend to generate more heat.

[2] Board on Radioactive Waste Management, National Research Council of the National Academies, *Safety and Security of Commercial Spent Nuclear Fuel Storage,* April 2005

the energy content is converted into electricity and only unusable products remain for disposal.

Several countries around the world, including Japan, Russia and France, currently reprocess their spent fuel with a process known as PUREX, short for plutonium-uranium extraction, in which plutonium and uranium streams are isolated from the remaining waste products. The fission products and minor actinides are cooled and then vitrified, or encased in glass, for long-term disposal. The uranium separated through PUREX is impure and can't be fabricated into fuel without further processing. As a result, the separated uranium is disposed of as low-level waste. The plutonium, on the other hand, can be mixed with freshly mined and enriched uranium to fabricate a mixed-oxide fuel known as MOX, which is recycled into reactors to generate more power. Plutonium can also be used to make weapons. Current practice in these countries is to reuse the plutonium only once and then dispose of the remaining waste rather than reprocessing and recycling a second time.

The Advanced Fuel Cycle Initiative at DOE

The Administration's May 2001 National Energy Policy recommended that the United States "develop reprocessing and fuel treatment technologies that are cleaner, more efficient, less waste-intensive, and more proliferation-resistant." The Advanced Fuel Cycle Initiative (AFCI) in the Nuclear Energy, Science and Technology Office at DOE has existed in various forms for many years, but adjusted its mission in response to the President's call for a return to reprocessing. The primary goals of the AFCI program are to: "develop technologies that will reduce the cost of geologic disposal of high-level waste from spent nuclear fuel, enhancing the repository performance [and] develop reactor fuel and fuel cycle technologies to support Generation IV nuclear energy systems."

Scientists working on AFCI are developing at least two reprocessing technologies, UREX+ and pyroprocessing, while continuing research on a new generation of technologies. The Department claims that both UREX+ and pyroprocessing have the potential to reduce U.S. nuclear waste problems while effectively managing proliferation and safety concerns. In UREX+, plutonium is never extracted in a pure stream—it remains mixed with neptunium and americium, two long-lived actinides that may act as proliferation deterrents by making the plutonium too toxic to handle without special equipment. In pyroprocessing, also known as "electro-metallurgical" processing, spent fuel rods are mechanically chopped, and the fuel is electrically separated into constituent products. This isolates the uranium while leaving the plutonium and other actinides mixed together. UREX+ is closer technologically to PUREX and is better suited than pyroprocessing for reprocessing the spent fuel from the current type of U.S. nuclear reactors, known as light water reactors.

Optimizing the fuel cycle

Reprocessing is only one of several steps that could be used to address nuclear waste problems. After actinides are separated from the waste stream, they can be further processed—"burned"—through a process called "transmutation." Transmutation, which requires a different type of nuclear reactor (such as a "fast reactor"), can generate electricity while reducing the toxicity of the actinides. Transmutation reduces the temperature of the waste products (radioactive materials are literally hot). This is significant because disposal sites, such as Yucca Mountain, can be limited in terms of the heat content they can accept as well as in terms of volume. Transmutation technologies have not yet been developed for other components of the nuclear waste stream.

Unless the U.S. also put into use transmutation technologies, reprocessing might be of less use. Reprocessing could increase the efficiency of nuclear fuel use and reduce the volume of waste, but without transmutation, it could not reduce the temperature ("heat load") of the waste sufficiently to allow Yucca Mountain to store more years of byproducts from nuclear generation.

In addition to pursuing reprocessing technologies, DOE has a program to develop the next generation of nuclear plants, known as Generation IV reactor designs that would be more energy efficient, proliferation-resistant and safer than the current fleet of reactors. Once DOE settles on a particular Generation IV design, it intends to sponsor a demonstration project, known as the Next Generation Nuclear Plant (NGNP) in Idaho. The NGNP also has the potential to make more efficient use of recycled plutonium as well as the other actinides to produce more electricity, possibly reducing the need for separate transmutation facilities in the future. However, spent fuel from some of the kinds of reactors being considered for the NGNP might not be able to be reprocessed using UREX+.

6. Witness Questions

Mr. Johnson

- What are the advantages and disadvantages of using reprocessing to address efficiency of fuel use, waste management and non-proliferation? How would you assess the advantages and disadvantages, and how might the disadvantages be mitigated?
- What are the greatest technological hurdles in developing and commercializing advanced reprocessing technologies? Is it feasible for the government to select a technology by 2007?
- To what extent will the Department have to modify its plans in order to comply with the report language accompanying the House-passed fiscal year 2006 Energy and Water Appropriations bill?
- What reprocessing technologies are currently under consideration? Is there one particular technology that is considered more promising than others?
- How should technology and policy decisions about other components of the fuel cycle influence the selection of a reprocessing technology?

Dr. Finck

- What are the advantages and disadvantages of using reprocessing to address efficiency of fuel use, waste management and non-proliferation? How would you assess the advantages and disadvantages, and how might the disadvantages be mitigated?
- What are the greatest technological hurdles in developing and commercializing advanced reprocessing technologies? Is it feasible for the government to select a technology by 2007?
- What reprocessing technologies currently are being developed at Argonne or at other National Labs? What technical questions must be answered?
- What reprocessing technologies are still in the basic research stage, what advantages might they offer, and what is the estimated timeline for development of laboratory-scale models?
- How would you contrast what is being done internationally with U.S. plans for reprocessing, recycling and associated waste management? What countries recycle now? What components of the waste fuel are or can be used to make new reactor fuel?

Dr. Hagengruber

- What are the advantages and disadvantages of using reprocessing to address efficiency of fuel use, waste management and non-proliferation? How would you assess the advantages and disadvantages, and how might the disadvantages be mitigated?
- What are the greatest technological hurdles in developing and commercializing advanced reprocessing technologies? Is it feasible for the government to select a technology by 2007?
- What kinds of research and development should the Department of Energy fund to ensure the proliferation resistance of future reprocessing technologies?

Mr. Bunn

- What are the advantages and disadvantages of using reprocessing to address efficiency of fuel use, waste management and non-proliferation? How would you assess the advantages and disadvantages, and how might the disadvantages be mitigated?
- What are the greatest technological hurdles in developing and commercializing advanced reprocessing technologies? Is it feasible for the government to select a technology by 2007?
- How should technology and policy decisions about other components of the fuel cycle influence the selection of a reprocessing technology? From your perspective, is the Department of Energy conducting the systems analysis required to make sound near-term technology decisions and guide long-term research and development?

Chairwoman BIGGERT. The hearing of the Subcommittee on Energy of the Committee on Science will come to order.

Good morning to you all. I want to welcome everyone to this hearing on nuclear fuel cycle and the potential for reprocessing and recycling to help us better manage the Nation's growing inventory of spent nuclear fuel.

To start, I want to quickly review our current situation to put today's hearing into some context. Twenty years from now, electricity demand in the United States is expected to increase by 50 percent. If we are to meet this incredible growth in demand without significantly increasing emissions of greenhouse gases, we must maintain a diverse supply of electricity, and nuclear power must be part of that mix. Nuclear energy is the only carbon-free source of electricity that is currently operating on a commercial scale nationwide. We know how to use nuclear energy, and we know how to use it safely. But if we are to continue to benefit from safe, emissions-free nuclear power for at least 20 percent of our electricity, there is at least one more issue that must be resolved: what do we do with the growing inventories of spent nuclear fuel?

Yucca Mountain was to be the solution. However, its intended opening slipped from 1998 to 2010, and now it is likely to slip again to 2012 or 2014, according to the Department of Energy. This failure to open Yucca Mountain as scheduled or deal with the spent fuel accumulating at our nuclear power plants in other ways may soon cost the Federal Government up to $1 billion annually in legal liability and interim storage costs. And when it does finally open, Yucca Mountain will be full. It is limited by statute to store only as much spent fuel as will have been created by 2010.

That Yucca Mountain, for all its intents and purposes, already is full should come to no surprise. If you think of nuclear fuel like a log, we currently burn only three percent of that log at both ends and then pull it out of the fire to bury it in a mountain. The bulk of what we call nuclear "waste" is actually nuclear "fuel" that still contains over 90 percent of its original energy content. Does that make any sense? No, but that is our current policy, and it is just plain wasteful. Unless we do something different or take another approach, a second repository, or an expanded Yucca Mountain, will be required. Politically, fiscally, and logistically, this will be no easy task, and could preclude greater use of emissions-free nuclear power.

For years now, scientists at DOE and a number of its national laboratories have been working on "new approaches" to dealing with commercial spent nuclear fuel and solving the long-term Yucca Mountain problem. More specifically, they have developed technologies and processes to do something with spent nuclear fuel besides bury it all in a mountain, like reprocess and then recycle parts of it into new fuel for reactors.

There are many advantages to these technologies, which have names like UREX+ and pyroprocessing. Let me just name a few.

First, they are proliferation resistant unlike the 30- to 40-year-old technologies already in use.

Second, they reduce the volume of our nuclear waste, which could render another Yucca Mountain unnecessary.

And third, they could reduce the toxicity, the heat and radioactivity, of the waste.

To fully realize these benefits and deal with the growing inventory of spent fuel, the fiscal year 2006 Energy and Water Appropriations bill, passed by the House last month, requires the Department of Energy to develop an integrated spent fuel recycling plan by the start of fiscal year 2007, and select a reprocessing technology by the end of fiscal year 2007. I am pleased, timing was perfect, that my colleague and author of that bill, Chairman Hobson, has joined us here today.

These activities could be the key to better managing our spent fuel. Reprocessing is just one step in the entire fuel cycle, the cradle-to-grave path of nuclear fuel. However, it is the first step to better managing our waste. We can learn lessons from what the French and Japanese have done with reprocessing. I know I did after visiting the French reprocessing facilities with Chairman Hobson in early April. We can continue to improve upon their technologies, processes, and monitoring capabilities.

But we almost certainly won't achieve these improvements without first doing a comprehensive systems analysis. Technology decisions for reprocessing must take into account technology and policy decisions for the entire fuel cycle. For example, we need to know if the reprocessing technologies under discussion here today are compatible with designs for the next generation nuclear plant. Through modeling that incorporates the relevant technical, economic, and policy considerations, this "systems approach" will allow us to optimize the fuel cell and make an informed decision about reprocessing.

Finally, how much could all of this cost? And that is a good and important question, which is why it will be the subject of another hearing at a later date.

This is a complex topic and one that involves many interrelated technical and policy issues. Yet the technologies and policies we will discuss today could help determine whether nuclear energy becomes an even more significant source of emissions-free electricity when we need it most in the years to come.

And so to conclude, I want to thank the witnesses for agreeing to share their knowledge and insight with us today. I look forward to an open and spirited debate on this very important subject.

[The prepared statement of Chairman Biggert follows:]

PREPARED STATEMENT OF CHAIRMAN JUDY BIGGERT

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To start, I want to quickly review our current situation to put today's hearing into some context. Twenty years from now, electricity demand in the United States is expected to increase by 50 percent. If we are to meet this incredible growth in demand without significantly increasing emissions of greenhouse gases, we must maintain a diverse supply of electricity, and nuclear power *must* be part of that mix. Nuclear energy is the only carbon-free source of electricity that is currently operating on a commercial scale nation-wide. We know how to use nuclear energy, and we know how to use it safely. But if we are to continue to benefit from safe, emissions-free nuclear power for at least 20 percent of our electricity, there is one more issue that must be resolved—what we do with growing inventories of spent nuclear fuel.

Yucca Mountain was to be *the* solution. However, its intended opening slipped from 1998 to 2010, and is now likely to slip again to 2012 or 2014 according to the Department of Energy (DOE). This failure to open Yucca Mountain as scheduled—or deal with the spent fuel accumulating at our nuclear power plants in other ways—may soon cost the Federal Government up to $1 billion annually in legal liability and interim storage costs. And when it does finally open, Yucca Mountain will be full. It is limited by statute to store only as much spent fuel as will have been created by 2010.

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Finally, how much could all this cost? That's a good and important question, which is why it will be the subject of another hearing at a later date.

This is a complex topic, and one that involves many interrelated technical and policy issues. Yet the technologies and policies we will discuss today could help determine whether nuclear energy becomes and even more significant source of emissions-free electricity when we need it most in the years to come. And so to conclude, I want to thank the witnesses for agreeing to share their knowledge and insight with us today, and I look forward to an open and spirited debate on this very important subject.

Chairwoman BIGGERT. And with that, I now recognize the—Mr. Honda, the Ranking Minority Member of the Subcommittee, for an opening statement.

Mr. HONDA. Thank you, Madame Chairwoman, and thank you for holding this very important hearing today.

From early on in the Nation's nuclear energy program, the "plan" to recycle, reprocess is the technical term, the fuel used in the reactor, to reduce the amount of material defined as waste and stretch the supply of available material needed for the generation of electricity.

Indeed, scattered across America are facilities that were built in anticipation of a "closed" back end fuel cycle, such as those at West Valley, New York, Morris, Illinois, and Barnwell, South Carolina.

These facilities never fulfilled their mission, however, because of two principal factors.

First, the Carter Administration's decision to abandon the reprocessing in the 1970s based on concerns raised about the proliferation of nuclear weapons, and second, economics.

The Reagan Administration reversed course on the issue of whether domestic reprocessing should serve as a tool in our nonproliferation policy, but even then no reprocessing began.

Then, as now, it didn't make economic sense to develop a domestic recycling capacity, partly because of the stagnation that developed in the U.S. nuclear energy construction program.

Also, the so-called "megatons to megawatts" program that takes Russian weapons-grade uranium and down-blends it to the lower concentrations needed for nuclear power reactors has helped to keep down the cost of reactor fuel, making reprocessing uneconomical.

Whether we like it or not, it seems clear that this Administration is leading us to a new era in the use of nuclear energy for the production of electricity over the next several decades.

This will create new demand for fuel, and the changing conditions may well make the economics of reprocessing as a means of supplying material for fuel more favorable.

Additionally, our nation is left with 50,000 metric tons of commercial spent fuel currently being stored at 73 sites in 33 states, and each nuclear power reactor continues to produce 20 tons of highly radioactive waste every year.

Even if a waste repository at Yucca Mountain opens and functions as planned, it would have only enough space to store the nuclear waste the United States is expected to generate by 2010.

If reprocessing can facilitate either a reduction in ultimate waste volumes or positively affect the challenge of isolating the ultimate waste form from the accessible environment, then perhaps we should assign some "value" to those societal goods, further affecting the economic balance.

In short, we may need to take a long-term approach to this issue and see if, indeed, it is not time to reexamine some fundamental tenets of U.S. fuel cycle policy.

But in doing so, we must be sure to be mindful of the threat any changes might pose in terms of nuclear proliferation.

At a time when the United States is seeking to discourage other nations from acquiring technologies that would produce weapon-usable plutonium, we do not want to send the signal that the United States is seeking to commercialize those very technologies.

I look forward to learning more from the witnesses about the state of the technology today, the economics surrounding that technology, and its nonproliferation implications.

Thank you again, Madame Chairwoman, and I yield back the balance of my time.

[The prepared statement of Mr. Honda follows:]

PREPARED STATEMENT OF REPRESENTATIVE MICHAEL M. HONDA

Madam Chairwoman, thank you for holding this important hearing today.

From early on in the Nation's nuclear energy program, the "plan" was to recycle, reprocess is the technical term, the fuel used in the reactor, to reduce the amount of material defined as waste and stretch the supply of available material needed for the generation of electricity.

Indeed, scattered across America are facilities that were built in anticipation of a "closed" back end fuel cycle, such as those at West Valley, NY, Morris, IL, and Barnwell, SC.

These facilities never fulfilled their mission, however, because of two principal factors:

First, the Carter Administration's decision to abandon reprocessing in the 1970's based on concerns raised about the proliferation of nuclear weapons; and second, economics.

The Reagan Administration reversed course on the issue of whether domestic reprocessing should serve as a tool in our non-proliferation policy, but even then no reprocessing began.

Then, as now, it didn't make economic sense to develop a domestic recycling capacity, partly because of the stagnation that developed in the U.S. nuclear energy construction program.

Also, the so-called "megatons to megawatts" program that takes Russian weapons-grade uranium and down-blends it to the lower concentrations needed for nuclear power reactors has helped to keep down the cost of reactor fuel, making reprocessing uneconomical.

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In short, we may need to take a long-term approach to this issue and see if indeed it is not time to re-examine some fundamental tenets of U.S. fuel cycle policy.

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At a time when the United States is seeking to discourage other nations from acquiring technologies that would produce weapon-usable plutonium, we do not want to send the signal that the U.S. is seeking to commercialize those very technologies.

I look forward to learning more from the witnesses about the state of the technology today, the economics surrounding that technology, and its non-proliferation implications.

Thank you again Madam Chairwoman, and I yield back the balance of my time.

Chairwoman BIGGERT. Thank you.

At this time, I would like to extend a warm welcome to my colleague from Ohio, Mr. Hobson, Chairman of the Energy and Water Development Appropriations Subcommittee. And I would ask unanimous consent that Chairman Hobson be allowed to sit in with the Committee and participate in today's hearing. Without objection, so ordered.

Chairman Hobson, would you like to say a few words?

Mr. HOBSON. Well, it is hard to say a few words when you are a Congressman, but I will try.

I want to thank the Chairwoman for allowing me to be here with all of you today, and I am really here to listen for a few moments. I do have to leave, but I want to demonstrate our support together with this committee and my Committee for the work that you are doing.

I think this is most important to the future of our country. Recycling, or reprocessing, is something that I think we need to do. Recently, we sent some material to France, and it was recycled and returned to this country where it is going to be burned in a nuclear power plant in this country. There aren't any dire consequences of doing all of that. It is too bad we couldn't do it here. This has a lot of economic benefit to this country in the future, and what we are trying to do is get the dialogue going and to get some real action.

I know that what we did in our bill is a little controversial, but it is a way to kick the can over to try to start people to talk about things and to get some new processes, if necessary. This is being done in the rest of the world. We need to relook at our policies that were determined probably 50 years or so ago. But I want to also say that I am very supportive of Yucca Mountain. I just don't want to get the Yucca Mountain II any sooner than we have to, and this is a way of not doing that.

But I want to thank you for the courage that you have taken to step forward, Madame Chairwoman, to raise this issue and to look at it from your Committee's standpoint, and I commend you for that. And thank you for allowing me to be here.

Chairwoman BIGGERT. Thank you very much for coming today.

And let us see. Any additional opening statements submitted by the Members may be added to the record.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. I want to thank the witnesses for appearing before our committee to examine the status of nuclear fuel reprocessing technologies in the United States. Every nuclear power reactor produces approximately 20 tons of highly radioactive nuclear waste every year. Today, the waste is stored on-site at the nuclear reactors in water-filled cooling pools, or at some sites, after sufficient cooling, in dry casks above ground. It is important to note that a recent report issued by the National Academy of Sciences concluded this stored waste could be vulnerable to terrorist attacks. Therefore, it is critical we begin to review our current nuclear waste policies and access possible policy options that may come before the Congress in the next few years.

Today's hearing marks the beginning of an important policy discussion on reprocessing technologies and the impact it will have on energy efficiency, nuclear waste management and weapons proliferation. I believe we should carefully examine the advantages and disadvantages of using reprocessing, and evaluate the policy options before making any decisions. At the same time, we cannot back away or retract from addressing critical national security concerns, such as nuclear waste management and weapons proliferation just because nuclear reprocessing is a controversial issue.

Within my home State of Illinois, the only nuclear engineering department is at the University of Illinois. This is particularly alarming because our state has 11 operating nuclear power reactors, Argonne National Laboratory, where Dr. Phillip Finck is from, and other nuclear facilities. Illinois residents have paid more than $2.4 billion on the federal Nuclear Waste Fund. My state has a large stake in nuclear power and technology and under-supported programs and initiatives that could improve upon our nuclear capabilities are quite troubling.

I am interested in hearing from our witnesses about the feasibility of selecting a reprocessing technology by 2007. Over time, technology will develop, interest will continue to grow, and economic circumstances may change in ways that point clearly in one direction. I believe we have an obligation to set aside sufficient funds so that we are not passing unfunded obligations on to our children and grandchildren, but not at the risk of implementing decisions prematurely, thereby depriving future generations of what might turn out to be better options developed later.

I welcome our witnesses and look forward to their testimony.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Examining nuclear fuel reprocessing technologies is a vital step in developing energy policy for the United States. Currently, this country relies on nuclear reactors for roughly 20 percent of our total energy. While nuclear energy provides less reliance on foreign oil and produces no greenhouse gas emissions, there is the persistent concern about nuclear waste. Today, this waste is stored on-site at the nuclear reactors power facilities. This is not only a safety concern, but also makes these facilities prime targets to terrorist attack. In order to move towards the future, we must examine the best methods to deal with this waste—whether it's through reprocessing or moving it to another location. This hearing is a key step in beginning this dialogue for the future.

Chairwoman BIGGERT. And with that, we will turn to our witnesses.

And I thank you all for coming this morning. And first of all, we have Mr. Shane Johnson, who is the Acting Director of the Office of Nuclear Energy, Science, and Technology and the Deputy Director for Technology at the Department of Energy. Next is Mr. Matthew Bunn, who is a Senior Research Associate in the Project on Managing the Atom at Harvard University's John F. Kennedy School of Government. Thank you for coming. And then Dr. Roger Hagengruber. I am going to stumble over that all day long. Hagengruber. He serves at the University of New Mexico as Director of the Office for Policy, Security, and Technology, Director of the Institute for Public Policy, and professor of political science, and he chairs the Nuclear Energy Study Group of the American Physical Society, which issued a May 2005 report: "Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risks." And last, but not least, is Dr. Phillip Finck, who is the Deputy Associate Laboratory Director, Applied Science and Technology and National Security at Argonne National Laboratory right in Illinois in my District. Welcome. And welcome to you all.

As the witnesses know, spoken testimony will be limited to five minutes each, after which the members will have five minutes each to ask questions.

And we will begin with Mr. Johnson. You are recognized for five minutes.

STATEMENT OF MR. ROBERT SHANE JOHNSON, ACTING DIRECTOR, OFFICE OF NUCLEAR ENERGY, SCIENCE AND TECHNOLOGY; DEPUTY DIRECTOR FOR TECHNOLOGY, U.S. DEPARTMENT OF ENERGY

Mr. JOHNSON. Chairman Biggert, Congressman Honda, Members of the Committee, and Chairman Hobson, I would like to thank you for the opportunity to speak today on the Department of Energy's efforts to develop and demonstrate advanced spent fuel separations and recycling technologies.

I have submitted a written statement for the record, but would like to provide a few summary remarks.

As you know, the President's National Energy Policy recommended the expansion of nuclear energy in the United States. To do this, we must also develop and apply advanced technologies, including advanced proliferation resistance, spent fuel treatment technologies, and next generation reactor technologies.

These fuel treatment technologies are aimed at safely and securely reducing the amount of commercial spent fuel requiring disposal in a geologic repository. These technologies, in combination with Generation IV reactors, hold the promise of deferring, perhaps indefinitely, the need for a second repository while reducing the inventory of civilian plutonium.

While the United States is a leader in the development of these technologies, it is important to note that other nations with domestic nuclear programs are also investigating similar technologies.

The policy underpinnings of our Advanced Fuel Cycle Initiative and our international cooperation is found in the May 2001 National Energy Policy, which states that the United States should consider technologies in collaboration with international partners with highly-developed fuel cycles and a record of close cooperation to develop fuel treatment technologies that are cleaner, more efficient, less waste-intensive, and more proliferation-resistant.

The technologies being developed in our Advanced Fuel Cycle program present a significant advantage in proliferation resistance over separation technologies currently being used in other parts of the world and which were previously used in the United States, namely the Plutonium-Uranium Extraction process, or PUREX. PUREX is an aqueous separations process that was deployed in the United States in the mid-1950s to separate high-purity plutonium and uranium from fission products and minor transuranic elements in irradiated nuclear fuels.

Over the last several years, our Advanced Fuel Cycle program has made significant progress in the development of advanced separation processes. We have successfully demonstrated the feasibility of the Uranium Extraction Plus, or UREX+, process at laboratory scale using actual spent nuclear fuel and are planning integrated experiments at larger scale. The UREX+ process is an advanced process that separates uranium from spent nuclear fuel at a very high level of purity. Unlike the PUREX process, UREX+ does not produce a separated plutonium product and thus provides a considerable advantage in reducing proliferation risks.

The Department is also investigating alternative separations technology, called pyroprocessing. Pyroprocessing technology employs high-temperature operations that use selective reduction and oxidation steps in molten salts and metals to recover nuclear materials.

The scale-up of these technologies from laboratory-scale to engineering-scale is possible with minimal technical risk. Using existing facilities, engineering-scale verification experiments could be underway in five to six years with possible commercial-scale operations possible in 10 to 12 years. Fuel fabrication experiments, as well as commercial-scale operations, would lag the demonstration of the separations technology by two to four years. However, modifying existing structures presents numerous technical and regulatory challenges.

An option to existing facilities is a greenfield approach for the engineering-scale demonstration. If such an engineering-scale operation were conducted in a new facility, the demonstration experiments could begin in approximately nine years, and it is anticipated that commercial—that would—that the technology would be commercially available within about 20 years. Again, fuel fabrication would lag, the separations work by about two to four years.

The Administration is currently examining recommendations of the Congress contained in the U.S. House of Representatives report accompanying the Energy and Water Development Appropriations bill for fiscal year 2006 specifically that the Department should inform a decision by fiscal year 2007 on a preferred separations technology and develop an integrated spent fuel management plan by that time that will ensure safe, secure, and efficient deployment of nuclear power around the globe.

We look forward to working closely with the Congress on what is a key issue to spent nuclear fuel management today and into the future.

Madame Chairman, this completes my statement, and I would be pleased to answer any questions you might have. Thank you.

[The prepared statement of Mr. Johnson follows:]

Prepared Statement of Robert Shane Johnson

Chairman Biggert, Ranking Member Honda, and Members of the Committee, I would like to thank you for the opportunity to speak before the Committee on Science, Subcommittee on Energy concerning United States and international efforts to develop and demonstrate advanced spent fuel separations and recycling technologies. Also, I thank you for your leadership in the area of nuclear energy technologies and for your interest in pursuing solutions to the Nation's challenges with the disposition of commercial spent nuclear fuel.

As you know, the President's 2001 National Energy Policy recommended the expansion of nuclear energy in this country to reduce our dependence on imported fuels needed for electricity generation and to reduce emissions. To meet these challenges, we must develop and apply advanced technologies, including advanced nuclear fuel cycles and next generation reactor technologies, and development of advanced fuel treatment technologies. These efforts are aimed at developing new advanced proliferation-resistant spent fuel treatment technologies to reduce the amount of commercial high level waste and spent fuel requiring storage in a geologic repository. If successful, these efforts could substantially improve repository capacity. In the longer-term future, these technologies in combination with advanced nuclear reactor technologies hold the promise of deferring, perhaps indefinitely, the need for a second repository, while reducing the inventory of civilian plutonium.

My testimony today focuses on U.S. efforts to develop new advanced separations technologies technologies that are more efficient, less waste intensive and more proliferation resistant—our progress in developing these technologies, and additional work that is needed to demonstrate commercial viability of these technologies. While the United States is a leader in development of these technologies, it is important to recognize that other nations (e.g., France, Japan, the United Kingdom, China, India, and Russia) with domestic nuclear programs are also investigating these technologies. Collaborations are also underway between the United States and several of these countries. A fundamental objective of U.S. collaborations is development of advanced proliferation resistant fuel cycle technologies that will set the standard for future international deployment of fuel cycle facilities.

BACKGROUND

The policy underpinnings of the Department of Energy's Advanced Fuel Cycle Initiative and its program for international cooperation with other countries is contained in the May 2001 National Energy Policy, which states that:

> ". . .in the context of developing advanced nuclear fuel cycles and next generation technologies for nuclear energy, the United States should re-examine its policies to allow for research, development and deployment of fuel conditioning methods that reduce waste streams and enhance proliferation resistance. In doing so, the United States will continue to discourage the accumulation of separated plutonium, worldwide."

The policy further states that the United States should consider technologies, in collaboration with international partners with highly-developed fuel cycles and a record of close cooperation, to develop fuel treatment technologies that are cleaner, more efficient, less waste-intensive, and more proliferation-resistant.

Inherent in this recommendation is the recognition that regardless of anticipated growth in nuclear generation, the Nation needs to establish a permanent geological repository for spent nuclear fuel from the operation of our existing commercial nuclear power plants. Further, growth in nuclear energy in the United States using the current spent fuel management approach would require construction of additional geologic repositories to address spent nuclear fuel inventories generated by the operation of additional nuclear power plants. However, development of advanced separations technologies present a potential alternative to building new repositories, optimizing the current geologic repository, and enabling more efficient use of our nuclear fuel resources.

As such, separations technologies are under development in the United States and by other countries to reduce the volume, toxicity, and fissile material content of spent nuclear fuel requiring the disposal in a permanent geologic repository. These advanced technologies are aimed at avoiding the proliferation issues associated with separated plutonium while resulting in significantly smaller quantities of high-level radioactive waste, enabling optimization of the geological repository.

These new technologies present a significant advantage in proliferation resistance over existing separations technologies being used in other parts of the world today and which were used previously in the United States—the Plutonium-Uranium Extraction (PURER) technology. PURER is an aqueous separations process that was deployed initially in the mid-1950s to recover high purity plutonium and uranium from fission products and minor transuranic elements (elements heavier than uranium). PURER has been deployed commercially in several countries—principally France, the United Kingdom, Japan and Russia.

In the future, we believe that advanced separations technologies, such as URanium EXtraction Plus (UREX+), could enable us to further extend the useful life of any geologic repository and reduce the radiotoxicity of the waste it contains such that it would decay to the toxicity of natural uranium ore in less than 1,000 years—instead of over 100,000 years as is the case with our current, untreated spent nuclear fuel. This technology could also allow our nuclear plants to use a far higher fraction of the energy contained in uranium ore, potentially expanding the lifetime of the world's nuclear fuel resources from around 100 years up to 1,000 years.

DEVELOPMENT OF INNOVATIVE SEPARATIONS TECHNOLOGIES

Over the last several years, the Department's Advanced Fuel Cycle Initiative has made significant progress in the development of new fuel treatment technologies, particularly as applied to the development of the UREX+ technology, a technology that separates uranium from spent nuclear fuel at a very high level of purity. This is important because it demonstrates the feasibility of greatly reducing the mass of material that would require disposal in a geologic repository. The research has also successfully demonstrated the ability to separate the short-term heat generating constituents of spent fuel and the partitioning of the transuranic elements. Unlike the PUREX process, the UREX+ process does not produce a separated plutonium product which provides a considerable advantage in reducing proliferation risk.

Presently, the Department has demonstrated the feasibility of the UREX+ process based on laboratory-scale tests using actual spent nuclear fuel. While the results from our laboratory-scale tests coupled with general industrial-scale experience could provide a high level of confidence that the general direction being recommended is technically feasible, integrated processing experiments carried out successfully at a larger engineering-scale would be needed before there is sufficient information to design and build new facilities or make needed major modifications to existing facilities for commercial-scale operations.

While the UREX+ process has great potential to address the spent fuel challenges associated with today's commercial light water reactors, the Department has also been investigating an alternative separations technology called pyroprocessing, which is more appropriate for treating advanced fuels from fast reactors like those under investigation in the Department's Generation IV reactor program that may be developed and deployed in the long-term future. The pyroprocessing technology employs high-temperature operations that use selective reduction and oxidation in molten salts and metals to recover nuclear materials. The pyrochemical processing technology is also supportive of nonproliferation objectives in that the resulting separated fuel material is adequate for use in fueling advanced fast-neutron spectrum reactors but represents a significant reduction in proliferation risk as the plutonium remains mixed with the other transuranic elements and fission products. The largest scale application of this technology is found at the Idaho National Laboratory where engineering-scale treatment of sodium-bonded spent nuclear fuel from the shutdown Experimental Breeder Reactor II has provided several years of research and operations data. At maximum capacity, this engineering-scale demonstration is capable of processing up to three metric tons of spent nuclear fuel annually.

DEVELOPMENT OF ADVANCED FUEL CYCLE TECHNOLOGIES

The United States presently employs a once-through fuel cycle—that is, the spent fuel is not recycled but rather discharged from the reactor and maintained in interim storage at the reactor site pending future shipment to a geologic repository. However, as discussed previously, a number of countries operate a partially closed fuel cycle in that the plutonium is removed from the spent fuel at a reprocessing facility and is sent to a fuel fabrication facility to be blended with fresh uranium and re-fabricated into mixed oxide (MOX) fuel pellets. The pellets are placed into cladding material and bundled into fuel assemblies for subsequent return to light water reactors capable of using MOX as fuel. The other spent fuel constituents are immobilized in glass for storage in a geologic repository. The Department is pursuing an approach similar to this one used by other countries to create MOX from surplus weapons grade plutonium.

The Department's Advanced Fuel Cycle Initiative fuels development includes proliferation-resistant fuels for light water reactors, fuels that will enable transmutation of transuranics in Generation IV reactors, and all fuels for the fast reactor group of Generation IV reactors. The objective of these technologies is to avoid separating plutonium in a pure form. The resultant mixed oxide fuel would contain some or all of the minor actinides (neptunium, americium and curium) contained in the spent fuel to enhance its proliferation resistance and allow for further reductions in the volume and radiotoxicity of the resulting high-level wastes. In each of these technologies, the benign residual fission products would be sent to a geologic repository with the exception of iodine-129 and strontium/cesium which would be disposed by means other than a geologic repository. These approaches are anticipated to increase the effective capacity of a geologic repository by a factor of 50 to 100.

In fast reactor scenarios, actinides from spent fuel can be processed to separate them from the bulk of the fission products and uranium. The actinide stream can then be used to manufacture fuel for use in fast reactors. Because the fuel is highly radioactive, the fuel fabrication process must be conducted in shielded facilities, conferring an additional degree of proliferation resistance.

Commercial scale-up of these spent fuel technologies can, based on our recent analysis, be performed relatively rapidly, if existing domestic facilities could be substantially modified and utilized. Using existing facilities, engineering-scale verification experiments for a chosen separation technology could be underway in five to six years and commercial-scale operations could begin in ten to twelve years. Fuel fabrication experiments and commercial-scale operations would lag the demonstration of the separations technology by two to four years. However, retrofitting existing structures to demonstrate commercial viability of spent fuel treatment presents numerous technical and regulatory challenges and may not be the most reasonable approach. For example, a down-side to retrofitting existing structures would be the current age of the structure and inherent inflexibilities such as the introduction and testing of modern instrumentation for process control, accountability and proliferation resistance.

An alternate scenario could be to build a "greenfield" engineering-scale demonstration facility that could provide assurance of the commercial viability of spent fuel treatment and fuel fabrication technologies. If both the engineering-scale and commercial-scale operations were conducted in new facilities designed from the ground up, engineering-scale experiments of a selected separations process could begin in approximately nine years and commercial operation, in about twenty. Again, fuel fabrication would lag by two to four years.

CONCLUSION

Over the last few years, the Department has successfully demonstrated the technical feasibility of advanced, proliferation-resistant fuel cycle technologies. Engineering-scale demonstrations, however, are needed to demonstrate with reasonable confidence the commercial feasibility of these technologies. We look forward to working closely with the Congress on the key issue of spent nuclear fuel management today and in the future.

I would be pleased to answer any questions you may have.

BIOGRAPHY FOR ROBERT SHANE JOHNSON

Shane Johnson is the Acting Director of DOE's Office of Nuclear Energy, Science and Technology. He was appointed to this position in May 2005, upon the resignation of the prior Director.

In this capacity, Mr. Johnson leads the Department's nuclear energy enterprise, including nuclear technology research and development; management of the Department's nuclear technology infrastructure; and support to nuclear education in the United States. Mr. Johnson also serves as the Lead Program Secretarial Officer for the Idaho National Laboratory, the Department's lead laboratory for nuclear technology research, development and demonstration.

Since 2000, Mr. Johnson has led the Office's nuclear technology initiatives, serving a key leadership role in the initiation and management of all of the Office's major research and development initiatives, including the Generation IV Nuclear Energy Systems Initiative, the Advanced Fuel Cycle Initiative, and the Nuclear Hydrogen Initiative. In 2004, Mr. Johnson was promoted to the position of Deputy Director for Technology, where his responsibilities also include management of the Nuclear Power 2010 program and initiatives aimed at strengthening university nuclear science and engineering programs in the United States.

Mr. Johnson serves a central role in the Department's efforts to reassert U.S. leadership in nuclear technology development. He led the formation of the *Generation IV International Forum* (GIF), an international collective of ten leading nations and the European Union's Euratom, dedicated to developing advanced reactor and fuel cycle technologies. He leads the Office's international cooperation activities, including establishment of cooperative research agreements with other countries and the development by the GIF of the Generation IV technology roadmap, which resulted in the selection of six promising reactor and fuel cycle technologies by the GIF for future development efforts. Mr. Johnson currently serves as the acting chairman of the GIF, pending election of a permanent chairman, and has served as the U.S. representative to the policy committee since 2001.

Mr. Johnson has over twenty years of relevant management and engineering experience within Government and industry. Prior to joining DOE, Mr. Johnson was employed for five years by Duke Power Company and Stoner Associates, Inc. where he was responsible for performing engineering studies for nuclear, natural gas, and water utilities.

Mr. Johnson received his B.S. degree in Nuclear Engineering from North Carolina State University and his M.S. degree in Mechanical Engineering from Pennsylvania State University. He is a licensed professional engineer.

Chairwoman BIGGERT. Thank you very much, Mr. Johnson.

And now Mr. Bunn, you are recognized for five minutes.

STATEMENT OF MR. MATTHEW BUNN, SENIOR RESEARCH ASSOCIATE, PROJECT ON MANAGING THE ATOM, HARVARD UNIVERSITY, JOHN F. KENNEDY SCHOOL OF GOVERNMENT

Mr. BUNN. Madame Chairwoman and Members of the Committee, it is an honor to be here today to discuss a subject that is very important to the future of nuclear energy and efforts to stem the spread of nuclear weapons, that is reprocessing of spent nuclear fuel.

I support limited continued R&D on advanced fuel cycle concepts that may offer promise for the future, but I believe a near-term decision to reprocess U.S. commercial spent nuclear fuel would be a serious mistake, with costs and risks far outweighing its potential benefits.

Let me make seven points to support that view.

First, reprocessing, by itself, does not make any of the nuclear waste go away. It simply separates—it is a chemical process that separates the radioactive materials into different components. Only if the added complexity of recycling or transmutation follows reprocessing is there a potential, not yet demonstrated, for destroying many of the long-lived radioactive materials. Whatever course we choose, we will still need nuclear waste repositories, such as Yucca Mountain.

As we heard, in the traditional process, known as PUREX, the spent fuel is separated into plutonium, which is weapons-usable, recovered uranium, and high-level waste. More advanced processes, like UREX+ and pyroprocessing, attempt to address some of the problems of PUREX, but whether they will do so successfully remains to be seen.

Second, reprocessing using current technologies or technologies available in the near-term would substantially increase, not decrease, the costs of nuclear waste management. In a recent Harvard study, we found, making assumptions quite favorable to reprocessing, that the costs of reprocessing and recycling would be about 80 percent higher than those of direct disposal, and other studies, including government studies in countries that are enthusiastic about reprocessing, such as France and Japan, have come to similar conclusions.

The one mill per kilowatt-hour nuclear waste fee would no longer be sufficient. Either the fee would have to be substantially increased, or tens of billions of dollars in taxpayer subsidies would have to be provided, or onerous regulations would have to be imposed to force the industry to build and operate the needed facilities itself.

The UREX+ technology now being researched adds a number of complex separation steps to the traditional PUREX approach and appears likely to further increase costs. Other processes might some day reduce costs, but this remains to be demonstrated. Official studies in recent years have predicted that the advanced processing and transmutation technologies being pursued would be more expensive than traditional approaches, not less.

Third, reprocessing and recycling using the technologies now commercially available means separating, fabricating, and transporting tons of weapons-usable plutonium every year, when even a few kilograms is enough for a bomb, inevitably raising proliferation risks not posed by direct disposal. It is crucial to understand that any state or group that could make a bomb from weapon-grade plutonium would also be able to make a bomb from the reactor-grade plutonium separated by reprocessing.

Moreover, a near-term U.S. return to reprocessing would make it more difficult to achieve President Bush's goal of convincing other countries not to build their own reprocessing facilities. The new approaches, as Mr. Johnson mentioned, are designed not to separate pure plutonium, but the plutonium-bearing materials that would be separated in either the UREX+ process or by pyroprocessing would not be radioactive enough to meet international standards for being very difficult to steal. And if these technologies were widely deployed in the developing world where most of the future growth in electricity demand will be, that would contribute to the spread of expertise, experience, and facilities that could be readily turned to a nuclear weapons program.

Fourth, while unfortunately no complete life cycle comparison of the safety and terrorism risks of reprocessing and direct disposal has yet been done, it seems clear that extensive processing of intensely radioactive fuel in the presence of highly volatile chemicals presents more opportunities for radioactive releases than simply leaving the fuel untouched in large casks.

Fifth, the waste management benefits that might be derived are quite limited. While the new technologies have, as their goal, reducing both the volume of waste to be disposed and its long-term hazard, the reality is that the projected radiological doses from geologic repositories are already quite low, and there are a variety of approaches to providing additional disposal capacity at Yucca Mountain or elsewhere without recycling, and these have not yet been adequately examined.

Sixth, the potential energy benefits are also quite limited. There is, indeed, quite a lot of energy in spent fuel, but in today's market, it is like oil shale: there is a lot of energy in it, but the cost of getting that energy out is much more than that energy is worth. World resources of uranium recoverable at prices far below those at which reprocessing would make sense are sufficient to fuel a growing global nuclear enterprise for many decades without recycling.

Seventh, and perhaps most important, there is no need to rush to make this decision. We have today a proven, commercially-available technology that will manage spent fuel cheaply, safely, and securely for decades, and that is dry casks, which utilities around the country are buying today. We can, and should, allow time for technology to develop further and for this decision to be made with care. Our generation does have an obligation to set aside enough funds so that future generations are not left with an unfunded obligation, but we have no obligation to rush to judgment. Our grandchildren will not thank us for implementing a technology today and depriving them of options that might be better that might be developed later.

Indeed, because the repository will remain open for 50 to 100 years, with spent fuel readily retrievable, proceeding forward with direct disposal would leave all options open for the future. It is a good thing that there is no need to rush, because the technologies available are at a very early stage of development. Only the most limited, as we heard, laboratory-scale experiments have been completed to date, and serious systems analysis of the costs of the different options, their safety and terrorism resistance, their proliferation impacts, prospects for licensing, and public acceptance have not yet been done.

I recommend that we follow the bipartisan advice of the National Commission on Energy Policy, which concluded that the United States should continue its moratorium on reprocessing, should expand interim spent fuel storage capacities, should proceed with all deliberate speed toward opening a permanent geologic waste repository, and should continue R&D on advanced fuel cycle approaches.

At the same time, the U.S. Government should redouble its efforts: to limit the spread of reprocessing and enrichment technologies around the world, as a critical element of President Bush's efforts to stem the spread of nuclear weapons; to ensure that every nuclear warhead and every kilogram of both plutonium and highly-enriched uranium worldwide is secure and accounted for, as a key element of our efforts to prevent nuclear terrorism; and to convince other countries to end the accumulation of plutonium stockpiles while working to reduce stockpiles of both plutonium and highly-enriched uranium around the world.

Some day, approaches to reprocessing and recycling may be developed that make sense. Research and development should explore such possibilities, but we should not rush to judgment now. If we want nuclear energy to grow enough to make a significant contribution to meeting the climate change challenge, that will require building support from governments, publics, and utilities around the world, and doing that means making nuclear energy as cheap, as simple, as safe, as proliferation-resistant, and as terrorism-proof as possible. Reprocessing using any of the technologies we have now or will have in the near-term points in the wrong direction on every count. And therefore, those who hope for a bright future for nuclear energy ought to oppose near-term reprocessing of spent nuclear fuel.

I would be happy to take your questions.

[The prepared statement of Mr. Bunn follows:]

PREPARED STATEMENT OF MATTHEW BUNN

The Case Against a Near-Term Decision to Reprocess Spent Nuclear Fuel in the United States

Madam Chairwoman and Members of the Committee: It is an honor to be here today to discuss a subject that is very important to the future of nuclear energy and efforts to stem the spread of nuclear weapons—reprocessing of spent nuclear fuel.

I believe that, while research and development (R&D) on advanced concepts that may offer promise for the future should continue, a near-term decision to reprocess U.S. commercial spent nuclear fuel would be a serious mistake, with costs and risks far outweighing its potential benefits. Let me make seven points to support that view.

First, reprocessing by itself does not make any of the nuclear waste go away. Whatever course we choose, we will still need a nuclear waste repository such as Yucca Mountain.[1] Reprocessing is simply a chemical process that separates the radioactive materials in spent fuel into different components. In the traditional process, known as PUREX, reprocessing produces separated plutonium (which is weapons-usable), recovered uranium, and high-level waste (containing all the other transuranic elements and fission products). In the process, intermediate and low-level wastes are also generated. More advanced processes now being examined, such as UREX+ and pyroprocessing, attempt to address some of the problems of the PUREX process, but whether they will do so successfully remains to be seen. Once the spent fuel has been reprocessed, the plutonium and uranium separated from the spent fuel can in principle be recycled into new fuel; in the more advanced processes, some other long-lived species would also be irradiated in reactors (or accelerator-driven assemblies) to transmute them into shorter-lived species.

More Expensive

Second, reprocessing and recycling using current or near-term technologies would substantially increase the cost of nuclear waste management, even if the cost of both uranium and geologic repositories increase significantly. In a recent Harvard study, we concluded, even making a number of assumptions that were quite favor-

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[1] Some residents of Nevada seem to see reprocessing, incorrectly, as an alternative to Yucca Mountain, but none of the strategies now proposed would eliminate the need for a repository for highly toxic nuclear waste. Indeed, it might surprise Nevadans to know that a stated purpose of the Advanced Fuel Cycle Initiative is to make it possible to bury the nuclear waste from a much larger quantity of electricity generation in Yucca Mountain—albeit after transmutation that, it is hoped, would reduce the long-term radioactive dangers posed by this waste.

able to reprocessing, that shifting to reprocessing and recycling would increase the costs of spent fuel management by more than 80% (after taking account of appropriate credits or charges for recovered plutonium and uranium from reprocessing).[2] Reprocessing (at an optimistic reprocessing price) would not become economic until uranium reached a price of over $360 per kilogram—a price not likely to be seen for many decades, if then. Government studies even in countries such as France and Japan have reached similar conclusions.[3] The UREX+ technology now being pursued adds a number of complex separation steps to the traditional PUREX process, in order to separate important radioactive isotopes for storage or transmutation,[4] and there is little doubt that reprocessing and transmutation using this process would be even more expensive. Other processes might someday reduce the costs, but this remains to be demonstrated, and a number of recent official studies have estimated costs for reprocessing and transmutation that are far higher than the costs of traditional reprocessing and recycling, not lower.[5]

To follow this course, either the current one mill/kilowatt-hour nuclear waste fee would have to be substantially increased, or billions of dollars in tax money would have to be used to subsidize the effort. Since facilities required for reprocessing and transmutation would not be economically attractive for private industry to build, the U.S. Government would either have to build and operate these facilities itself, give private industry large subsidies to do so, or impose onerous regulations requiring private industry to do so with its own funds. All of these options would represent dramatic government intrusions into the nuclear fuel industry, and the implications

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[2] See Matthew Bunn, Steve Fetter, John P. Holdren, and Bob van der Zwaan, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel* (Cambridge, MA: Project on Managing the Atom, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, December 2003, available as of June 9, 2005 at http://bcsia.ksg.harvard.edu/BCSIA_content/documents/repro-report.pdf). For quite similar conclusions, see John Deutch and Ernest J. Moniz, co-chairs, *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge, MA: Massachusetts Institute of Technology, 2003, available as of June 9, 2005 at http://web.mit.edu/nuclearpower/). The MIT study presents the results of its fuel cycle cost calculations differently, comparing the cost of a new low-enriched uranium fuel element to those of a new plutonium fuel element, assigning all the costs of reprocessing to the plutonium incorporated in the new fuel element, rather than considering reprocessing as part of the cost of spent fuel management and comparing the cost of managing a fuel element by direct disposal to those of managing it by reprocessing and recycling, as the Harvard study does. But these are differences of presentation, which have no effect on the estimated per-kilowatt-hour costs of the two fuel cycles; with the exception of a few differences in assumptions (more favorable to reprocessing in the case of the Harvard study), the conclusions of the two studies on the economics are very similar.

[3] France and Japan have been two of the countries most dedicated to reprocessing spent nuclear fuel; in both countries, and in the U.K., reprocessing continues not because it is economic but because of the inertia of past decisions and investments, the lack of available space for multi-decade interim storage of spent fuel, and arguments that the process will eventually have environmental and energy-security benefits. The French study compared a scenario in which all of the low-enriched uranium fuel produced in French reactors was reprocessed to a hypothetical scenario in which reprocessing and recycling had never been introduced, and found that not reprocessing would have saved tens of billions of dollars compared to the all-reprocessing case, and would have reduced total electricity generation costs by more than five percent. See Jean-Michel Charpin, Benjamin Dessus, and René Pellat, *Economic Forecast Study of the Nuclear Power Option* (Paris, France: Office of the Prime Minister, July 2000, available as of December 16, 2003 at *http://fire.pppl.gov/eu_fr_fission_plan.pdf),* Appendix 1. In Japan, the official estimate is that reprocessing and recycling will cost more than $100 billion over the next several decades. Studies performed by both the government and the utilities a decade ago concluded that direct disposal of spent fuel would be much less costly; new analyses performed for an advisory committee to the Japan Atomic Energy Commission in 2004 came to similar conclusions. See, for example, Mark Hibbs, "AEC Advisory Panel Clears Japan's Rokkashomura for Reprocessing," *Nuclear Fuel,* November 8, 2004; and Mark Hibbs, "Japan's Look at Long-Term Policy May Solve Rokkashomura Puzzle," *Nuclear Fuel,* July 19, 2004. The government's withholding of the data on these past studies caused a scandal in Japan. In France, the electric utility is state-owned, and so can be directed to pursue reprocessing even if it is the more expensive approach; in Japan, the utilities are seeking legislation that would subsidize the costs of reprocessing with a government-imposed charge to all electricity users.

[4] George F. Vandegrift et al., "Designing and Demonstration of the UREX+ Process Using Spent Nuclear Fuel," paper presented at "ATALANTE 2004: Advances for Future Nuclear Fuel Cycles," Nimes, France, June 21–24, 2004, available as of June 10, 2005 at *http://www.cmt.anl.gov/science-technology/processchem/Publications/Atalante04.pdf.*

[5] See, for example, Organization for Economic Cooperation and Development, Nuclear Energy Agency, *Accelerator-Driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles: A Comparative Study* (Paris, France: NEA, 2002, available as of December 16, 2003 at *http://www.nea.fr/html/ndd/reports/2002/nea3109-ads.pdf),* p. 211 and p. 216; U.S. Department of Energy, Office of Nuclear Energy, *Generation IV Roadmap: Report of the Fuel Cycle Crosscut Group* (Washington, DC: DOE, March 18, 2001, available as of July 25, 2003 at *http://www.ne.doe.gov/reports/GenIVRoadmapFCCG.pdf.),* p. A2–6 and p. A2–8.

of such intrusions have not been appropriately examined. I am pleased that the Subcommittee plans a later hearing with representatives from the nuclear industry to discuss these economic and institutional issues.

Unnecessary proliferation risks

Third, traditional approaches to reprocessing and recycling pose significant and unnecessary proliferation risks, and even proposed new approaches are not as proliferation-resistant as they should be. It is crucial to understand that any state or group that could make a bomb from weapon-grade plutonium could make a bomb from the reactor-grade plutonium separated by reprocessing.[6] Despite the remarkable progress of safeguards and security technology over the last few decades, processing, fabricating, and transporting tons of weapons-usable separated plutonium every year—when even a few kilograms is enough for a bomb—inevitably raises greater risks than not doing so. The dangers posed by these operations can be reduced with sufficient investment in security and safeguards, but they cannot be reduced to zero, and these additional risks are unnecessary.

Indeed, contrary to the assertion in the Energy and Water appropriations subcommittee report that plutonium reprocessing in other countries poses little risk because the plutonium is immediately recycled as fresh fuel—a conclusion that would not be correct even if the underlying assertion were true—the fact is that reprocessing is far outpacing the use of the resulting plutonium as fuel, with the result that over 240 tons of separated, weapons-usable civilian plutonium now exists in the world, a figure that will soon surpass the amount of plutonium in all the world's nuclear weapons arsenals combined. The British Royal Society, in a 1998 report, warned that even in an advanced industrial state like the United Kingdom, the possibility that plutonium stocks might be "accessed for illicit weapons production is of extreme concern."[7]

Moreover, a near-term U.S. return to reprocessing could significantly undermine broader U.S. nuclear nonproliferation policies. President Bush has announced an effort to convince countries around the world to forego reprocessing and enrichment capabilities of their own; has continued the efforts of past administrations to convince other states to avoid the further accumulation of separated plutonium, because of the proliferation hazards it poses; and has continued to press states in regions of proliferation concern not to reprocess (including not only states such as North Korea and Iran, but also U.S. allies such South Korea and Taiwan, both of which had secret nuclear weapons programs closely associated with reprocessing efforts in the past). A U.S. decision to move toward reprocessing itself would make it more difficult to convince other states not to do the same.

Advocates argue that the more advanced approaches now being pursued would be more proliferation-resistant. Technologies such as pyroprocessing are undoubtedly better than PUREX in this respect. But the plutonium-bearing materials that would be separated in either the UREX+ process or by pyroprocessing would not be radioactive enough to meet international standards for being "self-protecting" against possible theft.[8] Moreover, if these technologies were deployed widely in the developing world, where most of the future growth in electricity demand will be, this would contribute to potential proliferating states building up expertise, real-world experience, and facilities that could be readily turned to support a weapons program.[9]

Proponents of reprocessing and recycling often argue that this approach will provide a nonproliferation benefit, by consuming the plutonium in spent fuel, which would otherwise turn geologic repositories into potential plutonium mines in the long-term. But the proliferation risk posed by spent fuel buried in a safeguarded repository is already modest; if the world could be brought to a state in which such repositories were the most significant remaining proliferation risk, that would be cause for great celebration. Moreover, this risk will be occurring a century or more

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[6] For an authoritative unclassified discussion, see *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives,* DOE/NN–0007 (Washington DC: U.S. Department of Energy, January 1997), pp. 38–39.

[7] The Royal Society, *Management of Separated Plutonium* (London: Royal Society, 1998, summary available at http://www.royalsoc.ac.uk/displaypagedoc.asp?id=11407 as of June 10, 2005.

[8] See Jungmin Kang and Frank von Hippel, "Limited Proliferation-Resistance Benefits From Recycling Unseparated Transuranics and Lanthanides From Light-Water Reactor Spent Fuel," *Science & Global Security,* forthcoming.

[9] For a discussion of the importance of these elements of proliferation resistance, see Matthew Bunn, "Proliferation Resistance (and Terror-Resistance) of Nuclear Energy Systems," lecture for "Nuclear Energy Economics and Policy Analysis," Massachusetts Institute of Technology, April 12, 2004, available as of June 10, 2005 at *http://bcsia.ksg.harvard.edu/BCSIA_content/documents/prolif-resist-lecture04.pdf.*

from now, and if there is one thing we know about the nuclear world a century hence, it is that its shape and contours are highly uncertain. We should not increase significant proliferation risks in the near-term in order to reduce already small and highly uncertain proliferation risks in the distant future.[10]

As-yet-unexamined safety and terrorism risks

Fourth, reprocessing and recycling using technologies available in the near-term would be likely to raise additional safety and terrorism risks. Until Chernobyl, the world's worst nuclear accident had been the explosion at the reprocessing plant at Khystym in 1957, and significant accidents at both Russian and Japanese reprocessing plants occurred as recently as the 1990s. No complete life-cycle study of the safety and terrorism risks of reprocessing and recycling compared to those of direct disposal has yet been done by disinterested parties. But it seems clear that extensive processing of intensely radioactive spent fuel using volatile chemicals presents more opportunities for release of radionuclides than does leaving spent fuel untouched in thick metal or concrete casks.

Limited waste management benefits

Fifth, the waste management benefits that might be derived from reprocessing and transmutation are quite limited. Two such benefits are usually claimed: decreasing the repository volume needed per kilowatt-hour of electricity generated (potentially eliminating the need for a second repository after Yucca Mountain); and greatly reducing the radioactive dangers of the material to be disposed.

It is important to recognize that reprocessing and recycling as currently practiced (with only one round of recycling the plutonium as uranium-plutonium mixed oxide (MOX) fuel) does not have either of these benefits. The size of a repository needed for a given amount of waste is determined not by the volume of the waste but by its heat output. Because of the build-up of heat-emitting higher actinides when plutonium is recycled, the total heat output of the waste per kilowatt-hour generated is actually higher—and therefore the needed repositories larger and more expensive—with one round of reprocessing and recycling than it is for direct disposal.[11] And the estimated long-term doses to humans and the environment from the repository are not noticeably reduced.[12]

Newer approaches that might provide a substantial reduction in radiotoxic hazards and in repository volume are complex, likely to be expensive, and still in an early stage of development. Most important, even if they achieved their goals, the benefits would not be large. The projected long-term radioactive doses from a geologic repository are already low. No credible study has yet been done comparing the risk of increased doses in the near-term from the extensive processing and operations required for reprocessing and transmutation to the reduction in doses thousands to hundreds of thousands of years in the future that might be achieved by this method.

With respect to reducing repository volume, while the Department of Energy (DOE) has not yet performed any detailed study of the maximum amount of spent fuel that could be emplaced at Yucca Mountain, there is little doubt that even without reprocessing, the mountain could hold far more than the current legislative limit. There are a variety of approaches to providing additional capacity at Yucca Mountain or elsewhere without recycling. Indeed, as a recent American Physical Society report noted, it is possible that even if all existing reactors receive license extensions allowing them to operate for 60 years, Yucca Mountain will be able to hold all the spent fuel they will generate in their lifetimes, without reprocessing.[13] While proponents of reprocessing and transmutation point to the likely difficulty of licensing a second repository in the United States after Yucca Mountain's capacity is filled, it is likely to be at least as difficult to gain public acceptance and licenses for the facilities needed for reprocessing and transmutation—particularly as such fa-

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[10] For a discussion, see John P. Holdren, "Nonproliferation Aspects of Geologic Repositories," presented at the "International Conference on Geologic Repositories," October 31–November 3, 1999, Denver, Colorado; available as of June 10, 1995 at *http://bcsia.ksg.harvard.edu/publication.cfm?program=CORE&ctype=presentation&item_*id=1.

[11] See, for example, Brian G. Chow and Gregory S. Jones, *Managing Wastes With and Without Plutonium Separation,* Report P–8035 (Santa Monica, CA: RAND Corporation, 1999).

[12] This is because the uranium and plutonium separated by the traditional PUREX process, not being very mobile in the geologic environment, are not significant contributors in models of the long-term radiation releases from a geologic repository.

[13] Nuclear Energy Study Group, American Physical Society Panel on Public Affairs, *Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk* (Washington, D.C.: American Physical Society, May 2005, available as of June 9, 2005 at *http://www.aps.org/public_affairs/proliferation-resistance),* p. 17.

cilities will likely pose more genuine hazards to their neighbors than would a nuclear waste repository.[14]

Limited energy benefits

Sixth, the energy benefits of reprocessing and recycling would also be limited. Additional energy can indeed be generated from the plutonium and uranium in spent fuel. But in today's market, spent fuel is like oil shale: getting the energy out of it costs far more than the energy is worth. In the only approach to recycling that is commercially practiced today—which involves a single round of recycling as MOX fuel in existing light-water reactors—the amount of energy generated from each ton of uranium mined is increased by less than 20 percent.[15] In principle, if, in the future, fast-neutron breeder reactors become economic, so that the 99.3 percent of natural uranium that is U–238 could be turned to plutonium and burned, the amount of energy that could be derived from each ton of uranium mined might be increased 50-fold.

But there is no near-term need for this extension of the uranium resource. World resources of uranium likely to be economically recoverable in future decades at prices far below the price at which reprocessing would be economic are sufficient to fuel a growing global nuclear enterprise for many decades, relying on direct disposal without recycling.[16]

Nor does reprocessing serve the goal of energy security, even for countries such as Japan, which have very limited domestic energy resources. If energy security means anything, it means that a country's energy supplies will not be disrupted by events beyond that country's control. Yet events completely out of the control of any individual country—such as a theft of poorly guarded plutonium on the other side of the world—could transform the politics of plutonium overnight and make major planned programs virtually impossible to carry out. Japan's experience following the scandal over BNFL's falsification of safety data on MOX fuel, and following the accidents at Monju and Tokai, all of which have delayed Japan's plutonium programs by many years, makes this point clear. If anything, plutonium recycling is much *more* vulnerable to external events than reliance on once-through use of uranium, whose supplies are diverse, plentiful, and difficult to cut off.

Premature to decide—and no need to rush

Seventh, there is no need to rush to make this decision in 2007, or in fact any time in the next few decades. Dry storage casks offer the option of storing spent fuel cheaply, safely, and securely for decades. During that time, technology will develop; interest will accumulate on fuel management funds set aside today, reducing the cost of whatever we choose to do in the long run; political and economic circumstances may change in ways that point clearly in one direction or the other; and the radioactivity of the spent fuel will decay, making it cheaper to process in the future, if need be. Our generation has an obligation to set aside sufficient funds so that we are not passing unfunded obligations on to our children and grandchildren, but it is not our responsibility to make and implement decisions prematurely, thereby depriving future generations of what might turn out to be better options developed later. Indeed, because the repository will remain open for 50–100 years, with the spent fuel readily retrievable, moving forward with direct disposal will still leave all options open for decades to come.

Similarly, there is no need to rush to set up new interim storage sites on DOE or military sites, and no possibility of performing the needed reviews and getting the needed licenses to do so by 2006, as the Energy and Water appropriations subcommittee proposed.[17] There is a legitimate debate as to whether such interim spent fuel storage prior to emplacement in a geologic repository should be centralized at one or two sites, or whether in most cases the fuel should continue to be stored at existing reactor sites. In any case, the government should fulfill its obligations to the utilities by taking title to the fuel and paying the cost of storage. At the same

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[14] For an initial discussion of these points, see Bunn, Fetter, Holdren, and van der Zwaan, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel,* pp. 64–66.

[15] John Deutch and Ernest J. Moniz, co-chairs, *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge, MA: Massachusetts Institute of Technology, 2003, available as of June 9, 2005 at *http://web.mit.edu/nuclearpower/*), p. 123. They present this result as uranium consumption per kilowatt-hour being 15 percent less for the recycling case; equivalently, if uranium consumption is fixed, then electricity generation is 18 percent higher for the recycling case.

[16] For discussion, see "Appendix B: World Uranium Resources," in Bunn, Fetter, Holdren, and van der Zwaan, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel.*

[17] See, for example, Allison Macfarlane, "Don't Put Waste on Military Bases," *Boston Globe,* June 4, 2005.

time, we should continue to move toward opening a permanent geologic repository as quickly as we responsibly can—in part because public acceptance of interim spent fuel storage facilities is only likely to be forthcoming if the public is convinced that they will not become permanent waste dumps.

Nor is there any need to rush on deciding whether a second nuclear waste repository will be needed. While existing nuclear power plants will have discharged enough fuel to fill the current legislated capacity limit within a few years, the reality is that it will be decades before sufficient fuel to fill Yucca Mountain has in fact been emplaced. We can and should defer this decision, and take the time to consider the options in detail. Congress should consider amending current law and giving the Secretary of Energy another decade or more before reporting on the need for a second repository.

Proponents of deciding quickly on reprocessing sometimes argue that such decisions are necessary because no new nuclear reactors will be purchased unless sufficient geologic repository capacity for all the spent fuel they will generate throughout their lifetimes has already been provided. I do not believe this is correct. I believe that if the government is fulfilling its obligation to take title to spent fuel and pay the costs of managing it, and clear progress is being made toward opening and operating a nuclear waste repository, investors will have sufficient confidence that they will not be saddled with unexpected spent fuel obligations to move forward. By contrast, if the government were seriously considering drastic changes in spent fuel management approaches which might major increases in the nuclear waste fee, investors might well wish to wait to see the outcome of those decisions before investing in new nuclear plants.

It is a good thing there is no need to rush, as we simply do not have the information that would be needed to make a decision on reprocessing in 2007. The advanced reprocessing technologies now being pursued are in a very early stage of development. As of a year ago, UREX+ had been demonstrated on a total of one pin of real spent fuel, in a small facility—and had not met all of its processing goals in that test.[18] Frankly, in my judgment there is little prospect that further development of complex multi-stage aqueous separations processes such as UREX+ will result in processes that will provide low costs, proliferation resistance, and waste management benefits sufficient to make them worth implementing in competition with direct disposal. Pyroprocessing has been tried on a somewhat larger scale over the years, but the process is designed for processing metals, and significant development is still needed to be confident in industrial-scale application to the oxide spent fuel from current reactors. Other, longer-term processes might offer more promise, but too little is known about them to know for sure.

So far, we do not have a credible life-cycle analysis of the cost of a reprocessing and transmutation system compared to that of direct disposal; DOE has yet to do any detailed estimate of how much spent fuel can be placed in Yucca Mountain, and of non-reprocessing approaches to extending that capacity; we do not have a realistic evaluation of the impact of a reprocessing and transmutation on the existing nuclear fuel industry; we do not have a serious evaluation of the licensing and public acceptance issues facing development and deployment of such a system; we do not have any serious assessment of the safety and terrorism risks of a reprocessing and transmutation system, compared to those of direct disposal; and we do not yet have assessments of the proliferation implications of the proposed systems that are detailed enough to support responsible decision-making. In short, now is the time for continued research and development, and additional systems analysis, not the time for committing to processing using any particular technology.

Recommendations

For the reasons just outlined, I recommend that we follow the advice of the bipartisan National Commission on Energy Policy, which reflected a broad spectrum of opinion on energy matters generally and on nuclear energy in particular, and recommended that the United States should:

(1) "continue indefinitely the U.S. moratoria on commercial reprocessing of spent nuclear fuel and construction of commercial breeder reactors;"

(2) establish expanded interim spent fuel storage capacities "as a complement and interim back-up" to Yucca Mountain;

(3) proceed "with all deliberate speed" toward licensing and operating a permanent geologic waste repository; and

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[18] Vandegrift et al., "Designing and Demonstration of the UREX+ Process Using Spent Nuclear Fuel."

(4) continue research and development on advanced fuel cycle approaches that might improve nuclear waste management and uranium utilization, without the huge disadvantages of traditional approaches to reprocessing.[19]

At the same time, the U.S. Government should redouble its efforts to: (a) limit the spread of reprocessing and enrichment technologies, as a critical element of a strengthened nonproliferation effort; (b) ensure that every nuclear warhead and every kilogram of separated plutonium and highly enriched uranium (HEU) worldwide are secure and accounted for, as the most critical step to prevent nuclear terrorism;[20] and (c) convince other countries to end the accumulation of plutonium stockpiles, and work to reduce stockpiles of both plutonium and HEU around the world. The Bush Administration should, in particular, resume the effort to negotiate a 20-year U.S.–Russian moratorium on separation of plutonium that was almost completed at the end of the Clinton Administration.

Similar recommendations have been made in the MIT study on the future of nuclear energy,[21] and in the American Physical Society study of nuclear energy and nuclear weapons proliferation.[22]

It remains possible that someday approaches to reprocessing and recycling will be developed that make security, economic, political, and environmental sense. Research and development should explore such possibilities. Continued investment in R&D on advanced fuel cycle technologies is justified, in part to ensure that the United States will have the technological expertise and credibility to play a leading role in limiting the proliferation risks of the fuel cycle around the world. But the leverage of these technologies in meeting the most serious energy challenges of the 21st century is likely to be somewhat limited in comparison to the promise of other potential future energy technologies, and the emphasis that nuclear fuel cycle R&D should receive in the overall energy R&D portfolio should reflect that.

The global nuclear energy system would have to grow substantially if nuclear energy was to make a substantial contribution to meeting the world's 21st century needs for carbon-free energy. Building the support from governments, utilities, and publics needed to achieve that kind of growth will require making nuclear energy as cheap, as simple, as safe, as proliferation-resistant, and as terrorism-proof as possible. Reprocessing using any of the technologies likely to be available in the near-term points in the wrong direction on every count.[23] Those who hope for a bright future for nuclear energy, therefore, should oppose near-term reprocessing of spent nuclear fuel.

BIOGRAPHY FOR MATTHEW BUNN

Matthew Bunn is a Senior Research Associate in the Project on Managing the Atom in the Belfer Center for Science and International Affairs at Harvard University's John F. Kennedy School of Government. His current research interests include nuclear theft and terrorism; security for weapons-usable nuclear material in the former Soviet Union and worldwide; verification of nuclear stockpiles and of nuclear

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[19] National Commission on Energy Policy, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges* (Washington, D.C.: National Commission on Energy Policy, December 2004, available as of June 9, 2005, at *http://www.energycommission.org/ewebeditpro/items/O82F4682.pdf*), pp. 60–61.

[20] For detailed recommendations, see Matthew Bunn and Anthony Wier, *Securing the Bomb 2005: The New Global Imperatives* (Cambridge, Mass., and Washington, D.C.: Project on Managing the Atom, Harvard University, and Nuclear Threat Initiative, May 2005, available as of June 10, 2005 at *http://www.nti.org/cnwm*).

[21] John Deutch and Ernest J. Moniz, co-chairs, *The Future of Nuclear Power: An Interdisciplinary MIT Study* (Cambridge, MA: Massachusetts Institute of Technology, 2003, available as of June 9, 2005 at *http://web.mit.edu/nuclearpower/*).

[22] Nuclear Energy Study Group, American Physical Society Panel on Public Affairs, *Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk* (Washington, D.C.: American Physical Society, May 2005, available as of June 9, 2005 at *http://www.aps.org/public_affairs/proliferation-resistance*).

[23] For earlier discussions of this point, see, for example, John P. Holdren, "Improving U.S. Energy Security and Reducing Greenhouse-Gas Emissions:The Role of Nuclear Energy," testimony to the Subcommittee on Energy and Environment, Committee on Science, U.S. House of Representatives, July 25, 2000, available as of June 10, 2005 at *http://bcsia.ksg.harvard.edu/publication.cfm?program=CORE&ctype=testimony&item_id=9*; and Matthew Bunn, "Enabling A Significant Future For Nuclear Power: Avoiding Catastrophes, Developing New Technologies, Democratizing Decisions—And Staying Away From Separated Plutonium," in *Proceedings of Global '99: Nuclear Technology—Bridging the Millennia,* Jackson Hole, Wyoming, August 30-September 2, 1999 (La Grange Park, Ill.: American Nuclear Society, 1999, available as of June 10, 2005 at *http://bcsia.ksg.harvard.edu/publication.cfm?program=CORE&ctype=book&item_id=2*).

warhead dismantlement; disposition of excess plutonium; conversion in Russia's nuclear cities; and nuclear waste storage, disposal, and reprocessing.

Before joining the Kennedy School in January 1997, he served for three years as an adviser to the Office of Science and Technology Policy, where he played a major role in U.S. policies related to the control and disposition of weapons-usable nuclear materials in the U.S. and the former Soviet Union, and directed a secret study for President Clinton on security for nuclear materials in Russia. Previously, Bunn was at the National Academy of Sciences, where he directed the two-volume study *Management and Disposition of Excess Weapons Plutonium.* He is a consultant to the Nuclear Threat Initiative, and a member of the Board of Directors of the Russian-American Nuclear Security Advisory Council (an organization devoted to promoting nuclear security cooperation between the United States and Russia), the Arms Control Association, and the Center for Arms Control and Nonproliferation.

Bunn is the author or co-author of a dozen books and book-length technical reports (most recently including *Securing the Bomb 2005: The New Global Imperatives*), and dozens of articles in magazines and newspapers ranging from *Foreign Policy* and *The Washington Post* to *Science* and *Nuclear Technology.* He appears regularly on television and radio. Bunn received his Bachelor's and Master's degrees in political science, specializing in defense and arms control, from the Massachusetts Institute of Technology in 1985. He is married to Jennifer Weeks, and lives in Watertown, Massachusetts. They have two daughters, Claire and Nina.

Chairwoman BIGGERT. Thank you.

Dr. Hagengruber, you are recognized for five minutes.

STATEMENT OF DR. ROGER HAGENGRUBER, DIRECTOR, OFFICE FOR POLICY, SECURITY AND TECHNOLOGY; DIRECTOR, INSTITUTE FOR PUBLIC POLICY; AND, PROFESSOR OF POLITICAL SCIENCE, UNIVERSITY OF NEW MEXICO

Dr. HAGENGRUBER. Thank you, Madame Chairman, and I appreciate the invitation by the Committee to——

Chairwoman BIGGERT. If you could, pull the mike a little bit closer to you. Thank you.

Dr. HAGENGRUBER. Thank you, Madame Chairman. I appreciate the invitation of the Committee to testify today.

As you mentioned earlier, the Nuclear Energy Study Group was convened by the American Physical Society's Panel on Public Affairs. We have a report, which we have submitted for the record. I—it treats several matters related to nuclear energy.

The first is related to the question of reprocessing. At this point, we don't see a foreseeable expansion of nuclear power in the United States that would make a qualitative change to the need for spent fuel storage, at least for a few decades. Even though Yucca Mountain may be delayed considerably, the interim storage of spent fuel in dry casks, it—the current sites, or at a few regional sites, is, we believe, safe and affordable, at least for a couple of decades into the future. So we believe that there is time to be able to take a more enduring and prudent decision with respect to reprocessing in regard to the issue of proliferation.

We have identified a number of areas in our report of proliferation-resistant and cost-effective technologies that we think should be pursued. Some of these are, in fact, being addressed in the Department of Energy. They include issues of integration of advanced safeguards into reprocessing systems, additional approaches to adulterating or making the material less attractive. But I think that a detailed examination by nuclear weapon experts of the viability of this material in a true national nuclear weapons program is desperately needed, and that is an extensive and rather detailed classified portion of research, which I do not believe, at this point, has been accomplished.

We think, in a way, it is in the best interest of the United States to maintain a reprocessing research program and to seek proliferation-resistant and cost-effective reprocessing technologies if they can be found. We don't oppose the eventual reprocessing but believe an early decision, given the current status, could threaten the growth of the use of nuclear energy in the future. And by the way, nuclear energy growth is something that the American Physical Society supports and supports quite strongly.

We don't think that we should force a decision that might diminish the growing momentum for nuclear energy. An early decision on reprocessing may not have the policy robustness that can sustain it through the next two decades of almost certain persistent threat of proliferation. From our decade's worth of work and public survey on nuclear matters at the University of New Mexico, we know that energy and waste management issues are not as volatile in the minds of the public as the issue of proliferation.

The goal of our recommendations here is straightforward. If reprocessing technology is determined to be adequately proliferation-resistant and cost-effective, reprocessing can emerge then as a consensus decision with industrial, scientific, political, and public support. The stronger the consensus, in my view, the more sustainable the momentum for nuclear energy, and the more assured that the schedule for proceeding with the nuclear fuel cycle for the rest of this century.

On the other hand, we recognize the importance of timetables and respect Chairman Hobson's desire to have people appear by 2007 with some decisions made, and we certainly applaud that, because it does tend to force people to move. We would suggest, perhaps, that maybe 2007 is a good time to look at the status of the development of technologies for this purpose. Maybe they will be ready to go forward. But when those hearings are held, we think that strong and vigorous discussions should occur over the proliferation-resistance associated with these technologies, not just in the United States, we are not the threat of proliferation, but if, in fact, pursued across the world.

Now we want to address one last item before completing my testimony, and that is the importance of reinvigorating research and development in technical safeguards for the International Atomic Energy Commission. Most of the technology today that has provided safeguards that detected programs in North Korea and in Iran is technology that was developed in a vigorous program conducted during the 1970s. This program at the time, in today's dollars, probably numbered some tens of millions of dollars. Today's investment in research and development for international safeguards is only a few million dollars, and is a very small amount of money considering the opportunities provided by the advanced technologies of this decade and the decade before. In addition, the expansion of enhanced safeguards by the International Atomic Energy Commission during the 1990s offers opportunities for monitoring that are unprecedented in the first two decades of the NPT.

There are a number of areas, just to illustrate the point, we know today how to produce cost-effective, internationally-acceptable, continuous monitoring through satellite links, providing assured security for an instance of air sampling systems that can be used in conjunction with reprocessing or enrichment facilities. It is literally impossible for such facilities to, in fact, create unapproved procedures or material without being detected in some fashion by that type of rigorous sampling. In addition, the control that we use frequently in our nuclear weapons, the things that have assured us with this very high reliability associated with nuclear things, can, in fact, be integrated into the operations of facilities, assuring more detectable capability on the part of the United States to be able to see the operation of facilities in unauthorized ways.

In conclusion, the extent to which nuclear power will be an enduring option to meet future energy requirements in many regions of the world depend upon the steps that Congress takes now to manage the associated proliferation risks. Prudent management requires pursuing proliferation-resistant technologies exclusively and developing international agreements that limit the spread of enrichment facilities and investing in a strong safeguards program.

Subject to your questions, that is my testimony, Madame Chairman.

[The prepared statement of Dr. Hagengruber follows:]

PREPARED STATEMENT OF ROGER HAGENGRUBER

Thank you Congresswoman Biggert and Members of the Subcommittee for the opportunity to testify.

I'm Roger Hagengruber. I am a physicist by training and currently Director of the Office for Policy, Security and Technology (OPS&T) at the University of New Mexico. From 1991 to 1999, I was Senior Vice President of Sandia National Laboratory directing their nuclear weapons programs. I spent much of my more than 30 years at Sandia in arms control and non-proliferation activities including several tours in Geneva as a negotiator.

I am also Chair of the Nuclear Energy Study Group (NESG), convened by the Panel on Public Affairs of the American Physical Society. We examined technical options for raising the barrier between nuclear power and nuclear weapons proliferation. With your permission, I would like to include a copy of the report in the hearing record.

We reached conclusions in three general areas: technical safeguards, proliferation resistance evaluation & design, and reprocessing.

Let me first say that I am presenting the consensus view of a diverse group of scientists who are experts on nuclear power and proliferation issues. Over the course of their careers, members of the NESG held positions as DOE Undersecretary of Energy, Chair of the DOE Nuclear Energy Research Advisory Committee, director of research for the Nuclear Regulatory Commission, and acting Assistant Secretary of Defense.

Over the course of several months of discussion, we developed a consensus position on reprocessing. Here are our three main points:

- *There is no urgent need to reprocess.*
- *Take the time to get the science right.*
- *Do no harm.*

Let me say a few words about each point.

No Urgency

No foreseeable expansion of nuclear power in the U.S. will make a qualitative change to the need for spent fuel storage over the next few decades. Even though Yucca Mountain may be delayed considerably, interim storage of spent fuel in dry casks, either at current reactor sites, or at a few regional facilities, or at a single national facility, is safe and affordable for a period of at least 50 years.

The U.S. can take some of the next ten years to evaluate technologies and make a more enduring and prudent decision on reprocessing.

Get the Science Right

A decision on reprocessing shouldn't outpace the science. DOE should take the necessary time to carry out more thorough reprocessing research to identify the most proliferation resistant and cost effective technology. Examples of areas of research that could be most useful are:

- — Detailed evaluations by nuclear weapons experts regarding the implications of the reprocessed material on a reliable yet concealable weapons program by a proliferating country.
- — Concepts for the integration of advanced safeguards (e.g., use control) into reprocessing systems.
- — Additional approaches to increasing the inherent protection of the reprocessed material by additional adulteration or other means.

And let me be clear, *it is in the best interests of the U.S. to maintain a reprocessing research program and seek a proliferation resistant and cost-effective reprocessing technology. We do not oppose eventual reprocessing, but believe an early decision, given the current status, could threaten future growth in the use of nuclear energy.*

We believe that by pursuing appropriate reprocessing technology that gives the highest priority to proliferation resistance, the U.S. retains the ability to influence future directions, both technical and institutional, of the international community.

Do No Harm

We should not force a decision that might diminish the growing momentum for nuclear power.

We should take a lesson from the past. More than forty years ago, the Atomic Energy Commission, in an effort to establish a self-sufficient, domestic commercial nuclear power industry, set in motion the transfer of nuclear fuel reprocessing from the Federal Government to private industry. In response to this call, Nuclear Fuel Services, a private company, built the West Valley plutonium reprocessing plant in upstate New York but without addressing economic and safety issues adequately. The plant began operating in 1966 and closed six years later to address safety, environmental and efficiency problems. It never re-opened. The costs for retrofitting were too high, and public concern about the plant had grown too large.

I think the lesson is clear: *we must be cautious and not rush into reprocessing again until the safety, proliferation and cost issues are well understood and have been addressed properly.*

The goal of our recommendations is straightforward: If a reprocessing technology is determined to be adequately proliferation resistant and cost-effective, reprocessing can emerge as a consensus decision with industrial, scientific, political, and public support.

That said, I have to make a confession. As a former VP of Sandia, I recognize the value of timetables. I understand the importance of Congressman Hobson requiring action by 2007.

Timetables keep programs from becoming endless academic exercises.

And while the science may not be able to deliver a proliferation resistant and cost-effective technology by 2007, that doesn't mean you don't try.

So, I applaud Congressman Hobson for challenging the scientists to deliver. That is an effective way to motivate programs.

Nevertheless, I think we should be cautious about our expectations. The lesson from the Nation's West Valley foray is that we must proceed carefully.

So, I would make a modest suggestion.

Yes, as Congressman Hobson requires, have the DOE report on the state of reprocessing science in 2007. But, instead of having DOE recommend a particular technology that "should" be implemented in 2007—I suggest that DOE identify the most promising technology at that juncture were a decision to be made to begin development and that its report include a detailed discussion of the relationship of the technology to the prospect of proliferation. And we must be realistic in our expectations. It may be that despite the best efforts of all involved, the most promising technology in 2007 may still not be satisfactory to all the necessary stakeholders.

I'm recommending a modest change of tone. The change keeps a reprocessing decision as a goal but maintains an open view on the ability to deliver a cost-effective and truly *proliferation resistant* technology by 2007.

The DOE is currently researching reprocessing technologies including pyroprocessing and UREX+. An aspect of assessing proliferation resistance is determining whether the intensity of radioactive "self-protection" of the resulting waste is sufficient to prevent or deter its clandestine development into a nuclear weapon.

Our study group considered the proliferation resistance of UREX+. Some members believed that the current version of UREX+ would create a plutonium byproduct so hot that it was incapable of being used to make a weapon. Others thought that UREX+ "self-protection" is lower than the "self-protection" of current U.S. fuel cycle waste.

Research is on going at DOE to settle this question. We'll see what the research bears out. But, based on my nearly 20 years of involvement in nuclear weapons design I'll make one observation. The ultimate assessment should not be based on whether it is *theoretically possible* to make a weapon from the waste. A meaningful assessment must evaluate practical factors associated with making a weapon: the level of technical sophistication, the willingness to assume risk, the financial resources available, and the likelihood of success. These are difficult factors to evaluate—some of them will require extensive classified treatment—but I urge DOE to approach the assessment in this manner.

If no cost-effective and proliferation resistant reprocessing technology emerges in 2007, then the U.S. will continue to promote its current path of open-cycle & enrichment. A number of experts are concerned that this path presents significant proliferation risks, as evidenced by Iran. I concur; the spread of centrifuge technology is a significant national security risk.

There are numerous proposals for new international agreements to limit the spread of enrichment technologies. In our report we examined technical steps to limit proliferation. These steps will be most effective when coupled with changes in institutional arrangements.

The first technological step is to improve the primary line of defense against proliferation—international technical safeguards.

Technical safeguards used by the International Atomic Energy Agency sound alarms as soon as nuclear systems stray from peaceful use. They have proven value. In North Korea, environmental sampling helped show that North Korea was making false claims about its reprocessing activities. In Iran, disclosures by opposition groups plus surveillance technologies and environmental sampling are revealing the status of Iran's nuclear program.

Most of the implemented safeguards technologies are the result of scientific work done decades ago. Proliferators are adaptive and motivated adversaries; yet, we are currently relying on technology that is almost as dated as a rotary phone. We must re-invigorate our safeguards R&D program. I'll mention two of the ten R&D focus areas identified in our report.

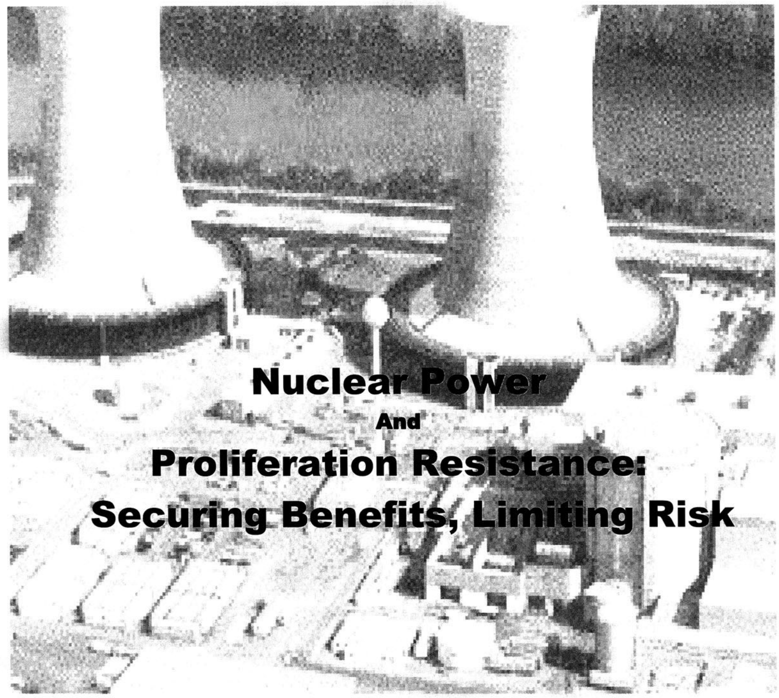
More inspectors carrying out more inspections is not a sustainable path—instead, next generation safeguards must spur a transition from the current system of periodic manual inspections to a reliable and cost-effective system of continuous remote monitoring. Also, more aggressive safeguards should be explored that would shut down a facility found to be violating international operating agreements. There are numerous other examples that represent "fruit ripe for the picking" as opposed to research that may never become practical. Additional progress in safeguards should involve collaborative research with international partners. In this regard, the large programs to improve the security of nuclear material in Russia and to assist in conversion offer major opportunities to advance joint safeguards concept to the IAEA.

Unfortunately, as we understand it, the current fiscal year 2005 international safeguards-related technology budget in NNSA (which we believe is already several times too small) was just reduced. At the very time when some would seek more rapid progress on the future of nuclear energy, modern safeguards and a deeper analysis regarding proliferation may be left in the dust. As a nation, we may live to regret our inadequate resources and emphasis in this area because for the future of nuclear energy, "ignorance is not bliss."

Another technical step to manage global proliferation risks is designing proliferation resistance technology directly into the new nuclear power plants and enrichment facilities. Making proliferation resistance a design criterion would re-shuffle the priority of future reactors. Some fuel-cycles would be deferred, while smaller, modular, reactor designs might receive more emphasis. By carrying out this step with commercial participation, proliferation resistance can emerge as a strength of our nuclear industry. We think that Congress should be very demanding regarding measures of proliferation resistance in any proposed further technical initiatives.

In conclusion, the extent to which nuclear power will be an enduring option to meeting future energy requirements in many regions of the world depends upon the steps Congress takes now to manage the associated proliferation risks. Prudent management requires exclusively pursuing proliferation resistant technologies, developing international agreements that limit the spread of enrichment facilities and investing in a strong safeguards program.

I'm happy to answer any questions.



Nuclear Power
And
Proliferation Resistance: Securing Benefits, Limiting Risk

A report by the
Nuclear Energy Study Group
of the American Physical Society Panel on Public Affairs

May 2005

PANEL ON PUBLIC AFFAIRS

THE NUCLEAR ENERGY STUDY GROUP

The American Physical Society is the nation's primary organization of research physicists with 43,000 members in industry, universities, and national laboratories. The APS Panel on Public Affairs occasionally produces discussion papers on topics currently debated in Congress in order to inform the debate with the perspectives of physicists working in the relevant issue areas.

The Nuclear Energy Study Group is composed of a broad range of experts. Together, they have considerable expertise in safeguards, nuclear-fuel cycle technologies, non-proliferation policy, international cooperation on nonproliferation R&D, and the management of federal nuclear technology programs.

For the complete bios of the authors see:
www.aps.org/public_affairs/proliferation-resistance/bios

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Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk

"Nuclear proliferation is a significant threat to America's security. We need to more consistently prevent the emergence of new nuclear weapons states, and to keep nuclear weapons capability out of terrorist hands. A comprehensive policy approach must address the many pathways that states or non-state actors may use to acquire nuclear weapons capabilities."
-- *House Policy Subcommittee on National Security & Foreign Affairs, January 2005*

Summary and Key Recommendations

Benefit: Meeting the Global Energy Demand

Global electricity demand is expected to increase by more than 50 percent by 2025. Nuclear power is a primary carbon-free energy source for meeting this extensive global energy expansion.

Risk: Proliferation and Nuclear Weapons

The technologies used in peaceful nuclear power programs overlap with those used in the production of fissionable material for nuclear weapons.

The elements of a nuclear power system include: facilities that mine and mill uranium ore, facilities that enrich uranium to create fuel, fuel fabrication facilities, reactors that burn that fuel to generate electricity, possibly facilities to reprocess the spent fuel, and waste storage sites.

Nuclear reactors themselves are not the primary proliferation risk; the principal concern is that countries with the intent to proliferate can covertly use the associated enrichment or reprocessing plants to produce the essential material for a nuclear explosive. Further, poorly secured nuclear materials present a risk of proliferation through theft and transfer to a country or terrorist groups.

Securing Benefits, Limiting Risk

The extent to which nuclear power will be an acceptable option to meeting future global energy requirements will depend upon its cost, safety, waste management, and the associated proliferation risks. While all these issues are important considerations, this report exclusively examines options for limiting proliferation risks.

No single diplomatic, military, economic, institutional, or technical initiative alone will be able to fully deal with this proliferation challenge. The best prospect for achieving non-proliferation goals while expanding nuclear power is to engage all appropriate means.

While nuclear power cannot be made "proliferation proof", this report examines technological steps that the US can take to enhance the resistance of nuclear power systems to theft, diversion and breakout. These technical steps will be most effective when coupled with changes in institutional arrangements.

Specifically, the US should:

General Recommendations

1. Significantly strengthen the federal Technical Safeguards R&D program: increase resources, identify near-term technology goals, formulate a technology roadmap, and improve interagency coordination.
2. Increase the priority of proliferation resistance in design and development of all future nuclear energy systems.
3. Develop & strengthen international collaborations on key proliferation-resistant technologies.
4. Align federal programs to reflect the fact that there is no urgent need to initiate reprocessing or to develop additional spent fuel repositories in the US.

Detailed Recommendations on pages: 13, 16, and 22.

National Security & Proliferation Resistance

Worldwide, thirty new nuclear plants were under construction in March 2005, with 20 new plants in Asia alone. In addition to China's plan to greatly expand its nuclear power program, Indonesia, Vietnam and Egypt have all declared an interest in building their first civilian nuclear power plants.

As evidenced by the current situation in Iran, technological advances and institutional changes are required to avoid proliferation by countries taking advantage of a global spread of nuclear power. Consequently, whether or not the United States constructs new nuclear power plants over the next quarter century, it is vital to US national security that the US remain engaged in the development of proliferation-resistant nuclear-energy technologies and of technologies that can support new international arrangements to safeguard and coordinate future fuel-cycle deployment.

Report Structure	
Section I	Overview of the benefits of nuclear power, the associated proliferation risks, and the need for action.
Section II	Summary of the primary federal R&D programs focused on strengthening proliferation-resistance of nuclear power.
Section III	Examination of the Technical Safeguards program. Recommendations that could enhance the proliferation resistance of nuclear power **within 5 years**.
Section IV	Examination of nuclear systems design and development programs. Recommendations that could enhance the proliferation resistance of nuclear power **over the next 10 to 30 years.**

Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk

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Section I

Overview

Goal: Secure the Benefits, Limit the Risk

The extent to which nuclear power will be a broadly accepted option for meeting future global energy needs depends upon cost, safety, waste management and the ability to limit the associated proliferation risks. While all four considerations are important, this report exclusively examines proliferation risks.

In particular, this report examines technical options that, taken together, can reduce the likelihood that a global expansion of nuclear energy would contribute to increased nuclear weapon proliferation. These technical options will be most effective when coupled with changes in institutional arrangements.

Nuclear Power and the Global Energy Future

Current global annual electricity consumption is roughly 15 trillion kilowatt-hours. Demand is growing rapidly and the Department of Energy projects that global annual consumption will exceed 23 trillion kilowatt hours by the year 2025.[1]

Numerous energy sources are available to satisfy this growing electricity demand including coal, natural gas, and nuclear power as well as renewable sources such as hydropower, biomass and wind. However, renewable energy sources offer only limited possibilities for achieving significant energy growth in the near term.[2] Domestic resources of natural gas have shown considerable price volatility, and international markets for natural gas are still in the early stages of development. Consequently, coal and nuclear power will be primary sources for many countries that are appreciably expanding their energy supply.

The coal option currently entails significant environmental costs such as those associated with carbon dioxide and particulate emissions, including possibly substantial changes in global climate with uncertain consequences.[3]

Nuclear power now meets roughly 17% of the global electricity demand and could make a significant contribution to carbon-free energy expansion.[4] Thirty nuclear plants were under construction in March 2005, with 20 new plants in Asia alone.[5]

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[1] Department of Energy, Energy Information Administration: http://www.eia.doe.gov/oiaf/ieo/pdf/tbl14.pdf

[2] "Ending the Energy Stalemate," National Commission on Energy Policy, December 2004, p vii: http://www.energycommision.org

[3] This problem would be ameliorated if technology can be developed to economically capture and sequester the carbon dioxide.

[4] "The Future of Nuclear Power: An Interdisciplinary MIT Study," http://web.mit.edu/nuclearpower/

[5] Nuclear Threat Initiative, http://www.nti.org/db/china/pwrrctr.htm

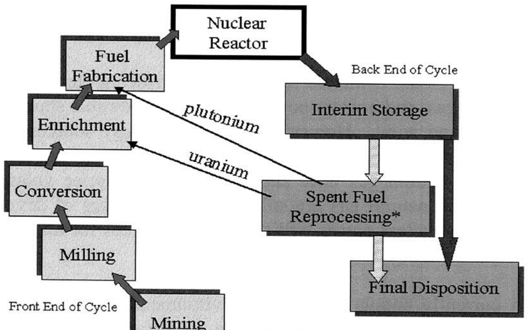
Given nuclear power's potential to reduce the dependence on fossil fuels, a balanced U.S. energy policy must keep open the nuclear energy option through the development and availability of nuclear plants and supporting infrastructure that can be built, operated, and eventually decommissioned in a safe, secure, environmentally sound and cost-effective manner.

Nuclear Power, Nuclear Proliferation and National Security

The technologies and materials used in the manufacture of nuclear weapons overlap with those used in peaceful nuclear power applications. The extent to which nuclear power will be an acceptable and enduring option to meeting future energy requirements in many regions of the world will therefore depend in part upon the ability to minimize the associated proliferation risks.

The elements of a nuclear power system include: facilities that mine and mill uranium ore, facilities that enrich uranium to create fuel, fuel fabrication facilities, reactors that burn that fuel to generate electricity, possibly facilities to reprocess the spent fuel,[6] and waste storage sites.

Elements of a Nuclear Power System (Fig 1)



*Spent Fuel Reprocessing is omitted from the cycle in most countries, including the United States

Nuclear reactors themselves are not the primary proliferation risk. The principal proliferation concern among the various elements of a nuclear power system are the enrichment and reprocessing facilities, which can produce materials directly usable in weapons. In addition, the spent fuel is a potential source of plutonium that must be safeguarded to prevent its clandestine separation for use in weapons, and fresh low-enriched uranium (LEU) fuel materials are a potential source for clandestine enrichment to nuclear weapons grade material. Further, poorly secured nuclear

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[6] "Reprocessing" is the term used for the chemical operations carried out to separate the fission products from the spent fuel and to separate and purify the uranium and plutonium.

materials, including plutonium separated for fabrication into reactor fuel, present a risk of proliferation through theft and transfer to another country or terrorist group.

The challenges to the non-proliferation regime are evident worldwide. Negotiations are under way to persuade Iran to abandon a uranium enrichment program, heavy water production plant and high-power research reactor that Iran claims are for civilian use but could easily be used to produce high-enriched uranium and plutonium for nuclear weapons. In North Korea, negotiations continue on termination of its nuclear weapons program and the associated reprocessing and enrichment activities. Much of Russia's approximately 2 million pounds of weapons usable uranium and plutonium from both military and civilian nuclear energy programs may not be satisfactorily secured.[7] Also, the smuggling network run by A.Q. Khan, who in the 1970s diverted uranium enrichment technology from a European consortium for use in Pakistan's nuclear weapons program, reportedly sold enrichment technology to several countries, including Libya.

This recent history leaves little doubt that civilian nuclear technology and materials can be misused, sold, stolen, or used as a cover for development of a nuclear weapons production capability. Figure 2 illustrates four primary pathways from nuclear-power programs to nuclear-weapons proliferation: *theft*, *sale*, *diversion*, and *breakout*.[8]

Pathways: From Nuclear Power to Nuclear Weapons (Fig 2)

THEFT	⇨	**SCENARIO** Nuclear material is stolen from poorly secured fuel fabrication or storage site or nuclear reactor.
SALE	⇨	**SCENARIO** A country or individual with access to a nuclear power program covertly sells nuclear material or enrichment and reprocessing technologies.
DIVERSION	⇨	**SCENARIO** A country with civilian nuclear power diverts uranium or spent fuel to a clandestine enrichment or reprocessing plant, where it is converted into weapons grade material.
BREAKOUT	⇨	**SCENARIO** An NPT signatory gains nuclear technology or stockpiles fissile material, then renounces the treaty and pursues nuclear weapons.

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[7] "Controlling nuclear warheads and materials", Harvard, Project on Managing the Atom, available at: http://www.nti.org/e_research/cnwm/overview/cnwm_home.asp

[8] For an overview of the technical issues see: http://www.ne.doe.gov/nerac/FinalTOPSRpt.pdf

Addressing the Proliferation Risks of Nuclear Power

There are a number of diplomatic, economic, military, and scientific and technical (S&T) approaches to reducing the proliferation risks of nuclear power.[9]

President Bush made a two part proposal to restrict the spread of enrichment and reprocessing technologies: 1) the world's leading nuclear exporters should ensure that states have reliable access at reasonable cost to fuel for civilian reactors, so long as those states renounce enrichment and reprocessing; and 2) The 40 nations of the Nuclear Suppliers Group 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.[10] IAEA director, Mohammed ElBaradei proposed a 5-year moratorium on construction of new enrichment or reprocessing plants while an effort is made to establish a multi-national alternative to nationally owned plants.[11]

Such fuel assurances and pledges to restrict sales are important components of a strategy to reduce the proliferation risks of nuclear power. [12] However, no single diplomatic, military, economic, or technical initiative alone will be able to fully deal with the proliferation challenge. The best prospect for achieving non-proliferation goals while expanding nuclear power is to engage all appropriate means and to maximize their respective contributions.[13]

From a technical point of view, nuclear power cannot be made "proliferation proof". However, numerous steps can be taken -- and must be taken -- to make it as "proliferation-resistant" as reasonably possible.

This is an urgent global security problem. China is poised to greatly expand its nuclear power program and Indonesia, Vietnam and Egypt have all declared an interest in building civilian nuclear power plants. Without technological advances and institutional changes, it will be easier for countries motivated to proliferate to take advantage of the global expansion of nuclear power or for terrorists to access nuclear materials. Iran's developing nuclear program indicates the urgent need to enhance the proliferation resistance of nuclear power.

Thus, whether or not the United States constructs new nuclear power plants over the next quarter century, it is vital to US national security that the US remain engaged in the development of proliferation-resistant nuclear-energy technologies and of technologies that can support any new arrangements to safeguard and internationalize the fuel-cycle and strengthen international institutions.

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[9] "Addressing the Challenge," http://www.iaea.org/NewsCenter/Statements/DDGs/2003/goldschmidt26112003.html
[10] President Bush, February 11, 2004: http://www.whitehouse.gov/news/releases/2004/02/20040211-4.html
[11] IAEA, 2005: http://www.iaea.org/NewsCenter/News/2005/npt_2005.html
[12] "Making the World Safe for Nuclear Energy," J Deutch, A Kanter, E Moniz, D Poneman, *Survival* , Vol. 46, No. 4, pp. 65-80: http://mit.edu/chemistry/deutch/policy/67MakingtheWorld2004.pdf
[13] "Options for Strengthening the Global Nuclear Nonproliferaiton Regime," Bengelsdorf, McGoldrick and Associates.

Section II

U.S. Proliferation-Resistance R&D Programs

There are four primary federal research and development (R&D) programs addressing proliferation resistance of nuclear power. There is considerable history behind the programs; this section provides only summaries.

The programs are located in the State Department and in the Department of Energy's Office of Nuclear Energy Science and Technology (DOE-NE) and National Nuclear Security Administration (NNSA). The budgets listed in Figure 3 are approximate.

Technical Safeguards

The goal of Safeguards R&D is to develop technologies that deter and detect theft and diversion and to provide early and clear indication of breakout. Such technologies are aimed at facility design verification, material control and accounting, nuclear material measurements, process monitoring and surveillance, environmental sampling, and remote monitoring.[14]

Proliferation Resistance & Physical Protection (PR&PP)

The goal of the PR&PP assessment program is to develop criteria to evaluate and compare proliferation resistance and physical protection of future nuclear energy systems, including reactors and their associated fuel cycle facilities.[15]

Generation Four Nuclear Energy Systems Initiative (Gen IV)

The goal of Gen IV is to "develop and demonstrate advanced nuclear energy systems that meet future needs for safe, sustainable, environmentally responsible, economical, proliferation-resistant and physically secure energy."[16]

The Advanced Fuel Cycle Initiative (AFCI)

The mission of the AFCI is to develop proliferation-resistant spent nuclear fuel treatment and transmutation technologies in order to enable a transition from the current once-through nuclear fuel cycle to a future sustainable, closed nuclear fuel cycle. This includes the development of advanced reprocessing technologies.[17]

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[14] International Atomic Energy Agency: http://www.iaea.org/Publications/Factsheets/English/S1_Safeguards.pdf
[15] Department of Energy: http://www.ne.doe.gov/infosheets/PRPPMay2004.pdf
[16] Department of Energy: http://gen-iv.ne.doe.gov/
[17] Department of Energy: http://www.ne.doe.gov/infosheets/afci.pdf

U.S. Proliferation-Resistance R&D Budgets in millions (Fig 3)

	FY '05
Technical Safeguards R&D (State Department, DOE-NE, NNSA)	less than $5 million[18]
PR & PP Assessment (DOE-NE, NNSA)	less than $1 million
AFCI (DOE-NE)	$68 million
Gen IV (DOE-NE)	$40 million

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[18] The *total* safeguards budget is much larger than $5 million and includes both domestic and international programs that largely implement or transfer technologies that are the result of R&D carried out 10 to 20 years ago.

Section III

Near-Term Approaches for Enhancing Proliferation Resistance: Technical Safeguards R&D

The current Safeguards program largely implements or transfers technologies that are the result of R&D carried out 10-20 years ago. Revitalizing Safeguards R&D is the most significant technical investment that can enhance the proliferation resistance of nuclear power within the next five years. The following section provides an overview of Safeguards and makes recommendations to strengthen and broaden the near-term impact of the federal Technical Safeguards program.

Safeguard Fundamentals

International Safeguards are a set of activities that the International Atomic Energy Agency (IAEA) uses to verify that a country is adhering to international commitments not to use its nuclear program for nuclear weapons purposes.

The safeguards system is based on regularly verifying the accuracy and completeness of a country's declarations to the IAEA concerning nuclear-related activities and seeking to assure that no undeclared nuclear materials or activities exist within the country. In total, more than 900 declared facilities in 71 countries are "safeguarded" and subject to inspection. [19]

Domestic Safeguards and security refer to measures taken by national authorities to protect and account for their nuclear materials holdings.

Technical Safeguards refers to the technologies used both in domestic and international safeguards to protect nuclear material facilities from theft and to verify that the material and facilities are being used exclusively for peaceful purposes.

Safeguards technologies cannot prevent proliferation. Their primary contribution is in establishing barriers that make *theft* and *diversion* more difficult and detectable and provide early and unambiguous warning. Thus, they provide assurances to both national regulators and international authorities that facilities and materials are protected against both national and sub-national threats.

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[19] International Atomic Energy Agency: http://www.iaea.org/Publications/Factsheets/English/S1_Safeguards.pdf

Safeguards also serve as confidence-building measures for countries to reassure their neighbors and the international community that they are in compliance with nonproliferation obligations. And, they are designed to provide the international community timely warning to intervene should a country be in breach of its commitments.

Consequently, technical safeguards complement diplomatic and legal efforts to restrain proliferation. Where institutional arrangements help to guide nations along peaceful nuclear pursuits, technical safeguards provide reassurance that their pursuits remain peaceful.

Investing in Safeguards R&D

Domestic and international safeguards have always relied heavily on technology. Although the need to protect and control nuclear materials, technologies, and facilities was recognized from the days of the Manhattan Project, during the mid-1960's to mid 1970's the US significantly expanded its R&D programs designed to improve nuclear materials security and international safeguards. During this period the Department of Energy and its predecessor organizations (AEC and ERDA) managed substantial technology development programs focused on improving technical safeguards. During this very active period of safeguards R&D, many of the technologies used globally today by the IAEA were developed.

There has been a long-standing recognition that having an application-oriented safeguard technology base directed to long-term capability improvement is essential to making meaningful progress in mission performance. In addition, the US has recognized the value in investing in the widespread application of technical safeguards, for example spending more than $1 billion through the Nunn-Lugar Program to improve the security of nuclear material in Russia.

Safeguards programs directed toward civil nuclear energy are spread over two agencies: the State Department and the Department of Energy, including its Office of Nuclear Energy Science and Technology and National Nuclear Security Administration.

Currently, what little safeguards R&D is being done is dispersed and the budget is less than $5 million. The *total* annual safeguards budget includes both domestic and international programs that largely implement or transfer technologies that are the result of R&D carried out 10 to 20 years ago.

Proven Value

Safeguards have been sufficiently effective to make theft and diversion from safeguarded facilities an unlikely path for proliferation in the past. Consequently, clandestine activities and covert facilities have become the more likely routes to obtaining nuclear materials. Even in such cases, technical safeguards including environmental sample analysis and surveillance analysis have proved effective.

Following the revelations about the Iraqi weapons program after the 1990 Gulf War, the technical safeguards of the IAEA were strengthened to include measures to improve the ability to detect undeclared activities.

In North Korea, environmental sampling helped to prove that North Korea was making false claims about its reprocessing activities. In Iran, disclosures by opposition groups supplemented by surveillance technology analysis and environmental sampling are revealing the status of Iran's nuclear program.

Safeguards Applications

The various elements of nuclear power generation are depicted in Figure 1. The figure shows both the "open" fuel cycle in which spent fuel is stored as waste and the "closed" fuel cycle in which the spent fuel is chemically reprocessed, some of the fissile components recycled in reactors for further use, and the highly radioactive fission products transformed to high level waste for disposal in a geological repository.

Each fuel cycle facility type requires safeguards. Enrichment plants, fuel fabrication facilities, reactors, reprocessing plants, and waste storage sites must all be monitored and present technical safeguards challenges.[20]

Revitalizing Safeguard Research and Development

Proliferators are adaptive. For technical safeguards to remain functional at containing *theft*, *diversion* and *breakout*, they must advance at least as quickly as a proliferator's techniques and potential opportunities.

Furthermore, technical advances provide opportunities to do more sophisticated and cost-effective monitoring. Technical safeguards must therefore be an ever-evolving response to proliferation challenges.

A robust safeguards R&D program is the single most significant technical investment that can be made to enhance the proliferation resistance of nuclear power in the near term. The investment in safeguards R&D will be most effective when coupled with changes in institutional arrangements, such as those that would limit the number of enrichment facilities.

As already noted, the potential growth of nuclear energy drives the need for greater efficiency to leverage limited inspection resources. Yet, the current federal safeguards program is primarily an implementation and technology transfer program and it must be enhanced to meet the challenge.

Figure 4 identifies some of the primary safeguard technical challenges.

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[20] For an introduction to these four technologies see: http://eia.doe.gov/cneaf/nuclear/page/intro.html For more technical background on these facilities: "Nuclear Energy : Principles, Practices, and Prospects" by D Bodansky, Springer, 1996.

Safeguard Technical Objectives (Fig 4)

ENRICHMENT PLANTS	**REACTORS AND FUEL FABRICATION**	**REPROCESSING PLANTS**	**WASTE SITES**
Detect concealed enrichment plants.	Detect concealed production reactors	Detect concealed reprocessing plants.	Detect diversion of nuclear material or spent fuel.
Detect production of highly enriched uranium or excess amounts of low enriched uranium in declared plants.[21]	Detect covert production of nuclear material.	Uncover undeclared use of facilities for separation or purification activities.	
	Uncover diversion of nuclear material from declared inventories.	Detect diversion of nuclear material.	

Key safeguards technologies to meet the detection objectives outlined in Figure 4 must be advanced to adequately limit the proliferation risks associated with the potential global expansion in nuclear power. However, the authors of this report learned in briefings from program directors at the State Department, the Department of Energy (DOE) and the National Nuclear Security Administration (NNSA) that there is no focused safeguards R&D budget or program providing a technology-base for nuclear materials security or international safeguards.

There *is* significant funding for technology transfer and implementation programs – most notably in the Cooperative Threat Reduction Program, the Material Protection, Control, and Accounting (MPC&A) program, and the Department of Homeland Security. However, for the most part, these programs rely on technology developed 20 years ago.

The urgent safeguards technology goals identified in Figure 4 will only be attained with a more structured and revitalized effort. The agencies participating in safeguard development should establish clear technology development goals for the next five years. For the longer term, a technology roadmap is needed to carry the program through subsequent stages of development. Such goals and roadmap will foster a consistent R&D base and help the US to promote the international importance of an enhanced technical safeguards agenda.

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[21] HEU: uranium containing any mixture of the isotopes ^{235}U and/or ^{233}U such that $(\%^{235}\mathrm{U} + {}^{5}/_{3}(\%^{233}\mathrm{U})) \geq 20\%\mathrm{U}$; LEU: enriched uranium containing lower amounts of ^{235}U and/or ^{233}U.

One office (NNSA/NN has the most appropriate technology and non-proliferation charter) should take the leadership role in coordinating an enhancement of the overall national safeguards R&D program. With a concentration of effort and appropriate management, it is possible that significant advances in safeguards technology can be achieved with modest increases in investment. At the same time, it is important to include the relevant experts in industry and the university communities.

Safeguard R&D Focus Areas

Technological advancements are needed in all safeguards areas in order to achieve more direct monitoring of nuclear facilities, more sophisticated methods for the IAEA to detect undeclared nuclear activities, and more advanced surveillance.

Indeed, one research and development goal of technical safeguards should be to spur a transition from the current system of periodic inspections to a system of continuous remote monitoring. Such an evolution of technology could provide more timely detection, reduce personnel costs and dramatically improve the barriers to theft, diversion and breakout. Such advancements in safeguards technology offer the only practical way of realizing the ideal goal of monitoring nuclear programs "at all times at all places".

Additional innovative safeguards technology paths should be explored such as, for example, the development of technology that can impede unauthorized operations. Such safeguards could be used to shut down a system or impede operation until help arrives in the event that a facility is violating operating agreements.

Specifically, nuclear security and international safeguards require improved:

- Detection methods including:
    - i. higher resolution, lighter weight, lower power, room-temperature radiation detectors;
    - ii. rapid, remote, tamper-resistant nuclear material item identifiers; and
    - iii. rapid, remote, unique, minimally intrusive personnel identifiers.
    - iv. fuel cycle facility process monitoring

- Quantitative assay methods for nuclear materials accounting including:
    - i. smaller, cheaper, more accurate, lower power, easier to calibrate and operate non-destructive assay systems for use throughout the fuel cycle; and
    - ii. faster, cheaper, environmental sample analysis.

- Systems integration including:
    1. improved information-management and analysis tools for the IAEA for open source analysis and commercial satellite imagery analysis;
    2. integration of data from disparate sensor types and automated anomaly detection; and
    3. design optimization of safeguards systems.

- Effectiveness evaluation including determining the best combinations of proliferation-resistance measures to employ for particular fuel cycle facilities.

Field Testing Safeguards – Models of Proliferation Resistance

Advanced safeguards technologies and systems must be field-tested if they are to perform reliably in fuel cycle facilities around the world. The R&D described above must be developed for use in real facilities and tested under conditions that are as representative as possible of the actual situations that the IAEA and national authorities face today and will encounter in the future. In some cases, this may require cooperative arrangements to work in operating commercial facilities in the US – where possible – or in foreign countries where such arrangements can be made. To maintain technical leadership, however, the United States needs to invest in representative test and evaluation facilities, such as making an enrichment facility at the Oak Ridge National Laboratory a model for technical safeguards. Noting the high cost of such facilities, consideration should be given to adapting the Fuel Material Examination Facility (FMEF) at Hanford for transuranic work. That facility was constructed to support the US fast breeder program that was terminated, and FMEF was never brought into operation.

New U.S. facilities should incorporate state-of-the-art safeguards systems developed in cooperation with the IAEA and thus serve as models to demonstrate to the international community advanced systems for IAEA safeguards. The new USEC Inc "lead cascade" at Portsmouth, Ohio and the proposed LES enrichment facility in New Mexico could provide near-term demonstrations and test beds for advanced centrifuge safeguards systems.[22]

International Collaborations

International cooperation in nuclear security and international safeguards technology development should be given higher national priority. International cooperation to enhance IAEA safeguards has gone on for many years with a number of countries. For example, Japan has a long history of productive collaboration with U.S. national laboratories to develop and demonstrate advanced technologies for use by the IAEA. Giving the DOE and the State Department the

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[22] http://www.nrc.gov/materials/fuel-cycle-fac/usecfacility.html

flexibility to expand such technical collaborations, in particular in regions anticipating significant growth in nuclear energy, will contribute to both safeguards technology development and to its rapid adoption.

The goal of collaborative efforts should be to design safeguards directly into critical nuclear systems and sub-systems from the outset.

Recommendations

- Significantly enhance the Technical Safeguards R&D program: increase resources, identify near-term technology goals, formulate a technology roadmap, and improve interagency coordination, and involve the commercial sector.
- Make future U.S. enrichment and/or reprocessing facilities models for proliferation resistance and technical safeguards.
- Expand efforts in international technical collaborations in safeguards R&D and pilot programs for advanced safeguards. A goal of the collaborations should be designing safeguards directly into critical nuclear systems.

Section IV

Long-Term Approaches for Enhancing Proliferation Resistance: New Nuclear Reactors & Fuel Cycles

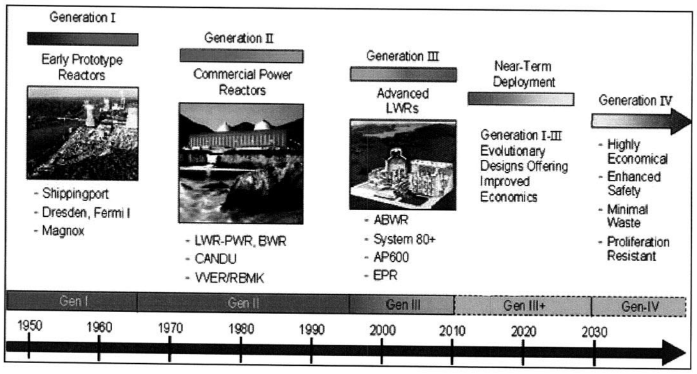
Nuclear systems design and development programs are long-term approaches to reducing proliferation risks. In general, the goal is to make future reactors and fuel cycles - 10 to 30 years from now - significantly more proliferation-resistant than current models and designs. The following sections examine these programs and provide recommendations that are intended to strengthen their contributions to enhancing proliferation resistance in the long-term.

A. Generation Four Nuclear Energy Systems Initiative (Gen IV)

Reactor Design: History

The first fifty years of the 20th Century was a period of rapid advancement in understanding nuclear science and technology. It took only a decade to advance from the discovery of the neutron in 1932 - and just four years from the discovery of fission in 1938 - to the construction of the first crude nuclear "reactor" under the University of Chicago's football stadium and the formation of the Manhattan Project that developed the first nuclear bomb.

The Evolution of Nuclear Power (Fig 5) [23]



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[23] Department of Energy: http://gen-iv.ne.doe.gov/

In the 1950's, the first generation of civilian nuclear power reactors - Gen I – was constructed. Companies that developed the technologies for nuclear bomb production became leaders in the rapid expansion of nuclear energy into electrical energy production. In 1954, Congress amended the Atomic Energy Act of 1946 to permit civilian ownership of nuclear material to facilitate the expansion of civilian use of nuclear energy. Government development of nuclear energy included emphasis on reactors that used enrichment facilities that were also used for nuclear weapons.[24] The influence of government priorities was the primary reason that enrichment became integral to the development of commercial reactors.

In the US, companies such as General Electric and Westinghouse (key contractors in the government programs of the 1940s and 1950s) developed light water designs that now dominate the power reactor industry in the U.S. and in most other parts of the world. These power plant designs (Gen II) provide a significant fraction of the electricity supply in many markets worldwide. More advanced designs of these reactors (Gen III) have been approved by nuclear licensing authorities, deployed in a few locations, and are ready for widespread deployment.

Recently the U.S. and nine other countries - Argentina, Brazil, Canada, France, Japan, Republic of South Africa, Republic of Korea, Switzerland, and the United Kingdom - anticipating that the world may be entering a period of expansion of nuclear energy, have joined in a collaboration to develop another generation of more advanced nuclear power systems (Gen IV).

Proliferation Resistance & Gen IV Development

The world and the U.S. may be entering a period of expansion of nuclear energy. International regimes to manage the new nuclear power systems have been proposed. President Bush has a two-part proposal involving fuel assurances and pledges to restrict sales.[25] IAEA director, Mohammed ElBaradei proposed a 5-year moratorium on construction of new enrichment and reprocessing plants while an effort is made to establish a multi-national alternative to nationally owned plants.[26]

In parallel with advancing new institutional structures, it remains important to assure that the proposed Gen IV technologies physically impede proliferation through all possible means. While cost and efficiency will dominate the interest of the commercial nuclear power sector in Gen IV decisions, the robustness of the non-proliferation regime will be a critical factor in sustaining support for nuclear energy in the decades ahead. Thus, future reactor design and development must reflect a high priority for proliferation resistance.[27] Recently, the countries participating in the Gen IV collaboration announced that six concepts would be pursued.[28] It is therefore urgent to establish shared priorities and constraints.

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[24] This facilitated the design of compact reactor for naval propulsion.

[25] President Bush, February 11, 2004: http://www.whitehouse.gov/news/releases/2004/02/20040211-4.html

[26] http://www.iaea.org/NewsCenter/News/2005/npt_2005.html

[27] Designing the fuels so that the intervals between refuelings were extended from a year or two to more than a decade would, for example, reduce frequency of access to the reactor fuel.

[28] http://www.energy.gov/engine/content.do?PUBLIC_ID=17543&BT_CODE=PR_PRESSRELEASES&TT_CODE=PRESSRELEASE

Proliferation-Resistance Criteria

The Department of Energy is in the process of developing proliferation-resistance criteria through its Proliferation Resistance and Physical Protection (PR&PP) Assessment. A goal of PR&PP is to produce criteria that can be used to evaluate GEN IV designs. A further goal of the PR&PP process is to generate standards that lead to a consistent framework for proliferation resistance, similar to the framework that exists for safety.

At this time, a methodology for constructing the PR&PP criteria has been drafted. The next step is to test and refine the methodology with nuclear systems designers. The program has no definite milestones beyond FY '06.

It is possible that PR&PP criteria will not provide clear and unequivocal guidance, but it is important to test whether practical criteria can be developed across the spectrum of nuclear energy alternatives. Therefore, funding for PR&PP should be sustained and the involvement of nuclear rector designers should be secured. To insure that it produces timely results, the DOE should also develop a timeline for the development of the intended proliferation-resistance framework.

Cost, safety, waste disposal, and proliferation resistance are all critical design issues for future nuclear systems. Yet, issues are typically prioritized in development of new technologies. Given the proliferation risks associated with the global expansion of nuclear energy, proliferation resistance should be a constraint on design and development of new systems.

Practically, this constraint means, for example, that Gen IV systems should be designed to fully integrate safeguard technologies that can continuously monitor and impede any misuse – advanced safeguards should be "built-in". Processes, designs, and initiatives that might be attractive on the basis of cost, performance, and other considerations should not be pursued if they are not proliferation-resistant or should be modified to assure the strongest barriers to proliferation.

Recommendations

- To support the development of practical proliferation resistance criteria that can lead to a consistent framework, the DOE should: maintain Proliferation Resistance and Physical Protection resources, secure nuclear reactor designers' involvement in the PR&PP assessment, and establish more detailed project timelines.
- Make proliferation resistance a constraint on future reactor design & development.

B. Fuel Cycle R&D

The Department of Energy Advanced Fuel Cycle Initiative Goals

One of the Department of Energy's stated primary goals for its AFCI program is to develop spent fuel treatment technologies that would significantly delay or eliminate the need for more than one national nuclear waste repository. A further stated DOE goal is to research technologies that would support the development of a closed nuclear fuel cycle, thereby decreasing the amount and changing the character of the material needing long-term geological disposal.[29]

Waste Disposal & Reprocessing: Background

Currently, spent fuel from U.S. nuclear power plants is stored on-site at the plants where it was produced. According to the plan laid out in the Nuclear Waste Policy Act of 1982 (NWPA), the Department of Energy (DOE) will remove this spent fuel from the plants and dispose of it in deep-geological repositories.[30] In 1987, the Congress amended the NWPA so that the first national repository would be built at Yucca Mountain, Nevada.[31]

The Yucca Mountain Repository is undergoing licensing challenges and at the very least it may be considerably delayed. Nevertheless, under current law, the Repository is limited to handling only a fraction of the waste that is expected to be generated by current US nuclear power plants.[32] Specifically, the Repository is limited to 70,000 metric tons of heavy metal [tHM] until a second repository has been put into operation.[33] Because 10 percent of this capacity is set aside for waste from the U.S. defense programs, only 63,000 tHM capacity is available for spent power-reactor fuel.[34] According to DOE projections, US reactors will have generated this amount of spent fuel by 2008. If, as currently expected, most US power reactors receive license extensions that allow them to operate until they are 60 years old, they will continue to discharge spent fuel at a rate of about 2,000 tHM per year until a total of 120,000-130,000 tHM has accumulated by around 2040. That is nearly twice the amount that is allowed to be disposed of at Yucca Mountain according to current law. However, the geological capacity of Yucca Mountain may be sufficient to hold it all.

The NWPA requires the Secretary of Energy to "report to the President and to Congress on or after January 1, 2007, but not later than January 1, 2010, on the need for a second repository."[35] Because the total amount of spent fuel from

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[29] A "closed cycle" is a nuclear system in which the spent fuel is reprocessed and its contained plutonium and perhaps other transuranic elements are recycled.

[30] NWPA, Sec. 302, a5B.

[31] NWPA, Sec. 160. The Nuclear Regulatory Commission (NRC) licensing process for the Yucca Mountain repository is on-going.

[32] Congressional testimony of Secretary of Energy Spencer Abraham, May 16, 2002.

[33] This includes both spent fuel and the radioactive waste from reprocessed spent fuel: NWPA, Sec114, d.

[34] *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada, [Final Yucca Mt EIS]* DOE/EIS-0250, 2002, Summary, http://www.ocrwm.doe.gov/documents/feis_2/summary/indexsum.htm

[35] NWPA, Sec. 161.

currently operating U.S. reactors is projected to exceed the currently legislated 63,000-tHM quota for Yucca Mountain by 2008, the Secretary will have to recommend either:

1) That a second repository is required, or
2) That Congress increase the legal limit on the amount of radioactive waste that can be placed in the first repository, or
3) That Congress defer any decision for some period.

Potential Reprocessing Benefit: Reduce the Waste Burden

Currently, the Department of Energy has no formal position about which of these options to recommend. But the desire to provide for the disposal of additional nuclear waste without building a new repository has led to a suggestion that reprocessing of nuclear waste could be used to reduce the quantity of nuclear material that would need to be disposed of at Yucca Mountain.

The Department of Energy responded to the reprocessing suggestion by shifting the emphasis of its Advanced Fuel Cycle Initiative (AFCI). In 2003, DOE reported to Congress that if spent fuel is reprocessed to remove the uranium and transuranic elements that it contains,[36] the Yucca Mountain repository might be able to hold the high-level waste from a much larger quantity of spent fuel and "potentially eliminate the technical requirement for a second [repository]."[37] The AFCI reprocessing program seeks to develop technical options to accomplish this.

The interplay between possible reprocessing strategies and high-level waste geological disposal is a complex one. The reduction of waste volume and mass are less important compared to other issues such as heat loads and surface storage times. And while such reprocessing strategies are important, they are not urgent.

Potential Reprocessing Risks: Proliferation & Nuclear Terrorism

While the spread of centrifuge enrichment technology is currently considered to be the principal proliferation threat, the reprocessing of spent nuclear fuel has inherent

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[36] "Transuranics" are elements with atomic numbers greater than uranium, created by neutron capture by uranium isotopes, and subsequent neutron captures and other decays. In spent LWR fuel, the most important transuranics are neptunium, plutonium, americium, and curium.

[37] The uranium would be disposed of as low-level waste or recycled. The transuranics would be recycled and fissioned partially in current-generation light-water reactors and partially in future fast-neutron reactors. For details see: *Report to Congress on Advanced Fuel Cycle Initiative: The Future Path for Advanced Spent Fuel Treatment and Transmutation Research* (U.S. DOE, Office of Nuclear Energy, Science, and Technology, 2003, p. II-4.

Partial chemical separation of the 30-year half-life fission products, cesium-137 and strontium-90, and their storage on the surface until they decay, would increase the effective capacity of the repository still further. See: "Spent nuclear fuel separations and transmutation criteria for benefit to a geological repository," by R. A. Wigeland, T.H. Bauer, T.H. Fanning, and E.E. Morris, Nuclear Engineering Division, Argonne National Laboratory, Waste Management 2004 Conference, Tucson, AZ, Feb. 29-March 4, 2004.

DOE is funding the development of spent-fuel reprocessing technologies that could accomplish the necessary separations of uranium, cesium with strontium, plutonium with technetium, and americium with curium: "Designing and demonstration of the UREX+ process using spent fuel" by G. F. Vandergrift *et al.*, Chemical Engineering Division, Argonne National Laboratory, Atlante Conference 2004, Nimes France, June 21-25, 2004.

proliferation risks.[38] Reprocessing using currently commercialized technologies leads to the generation of separated plutonium, which can be directly used to manufacture nuclear weapons.[39] Consequently, reprocessing technologies can create risks of *diversion*, *sale* and *breakout*. Where reprocessing involves the handling, transport, and storage of weapons-usable plutonium and fuels containing plutonium, there is an associated risk of *theft*.

Worldwide, about 240 declared tons of separated plutonium have been stockpiled as a result of civilian reprocessing programs, primarily in France, the United Kingdom, Russia and Japan. The stockpiles are still increasing.[40]

In countries with stable societies and high standards of security and accounting and personnel reliability, the risks of theft are less, though not negligible. Even in stable Britain, the Royal Society warned in 1998 that "the chance that the [British] stocks of plutonium might, at some stage, be accessed for illicit weapons production is of extreme concern."[41] Clearly, the dangers are higher in countries with low standards of security or high dangers of penetration by terrorists.

Currently, the US does not reprocess spent nuclear fuel.[42] In the absence of reprocessing, the stored spent fuel emits intense radiation from the long-lived fission products that are mixed with the other elements in the fuel. The radiation deters theft and makes separation of weapon-useable fissile materials difficult.[43] Indeed, unprocessed spent fuel can be a much more theft-resistant storage form for at least a century than reprocessed fuel which is protected only by the relatively weak radiation from the fissile material alone.[44]

The US adopted a no-reprocessing policy in the mid-1970s after India used plutonium separated for "peaceful purposes" to develop a nuclear explosive. Other countries, including Brazil, Pakistan, South Korea, and Taiwan, sought to follow India's example by launching "civilian" reprocessing programs. In each case,

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[38] It could also have significant negative effects on the economics of nuclear power. A French government commission concluded that if France ceased reprocessing in 2010, it will reduce the cost of nuclear electricity by about 0.5 mil per kw-hr or about 1% over the remaining lifetime of its current fleet of power reactors. See: *Economic Forecast Study of the Nuclear Power Option* (Planning Commission, Government of France, 2000); available at, Section 3.4 http://fire.pppl.gov/eu_fr_fission_plan.pdf

[39] "U.S. Fuel Cycle Policy," National Security Policy Directive 17 (2002).

[40] France, the United Kingdom, and Russia are already nuclear-weapon states and the United Kingdom has decided to end its reprocessing program, but Japan appears to be about to launch operations at a major new reprocessing plant.

[41] *Management of Separated Plutonium,* (London, The Royal Society, 1998) Summary.

[42] "U.S. Fuel Cycle Policy," National Security Policy Directive 17 (2002).

[43] Weapon-usable transuranics (primarily plutonium) are diluted by 100 times as much uranium in the spent fuel and protected by the intense gamma radiation generated by fission products. After ten years, this radiation comes primarily from cesium-137.

[44] "Dose Rate Estimates from Irradiated Light-Water-Reactor Fuel Assemblies in Air" by W.R. Lloyd, M.K. Sheaffer and W.G. Sutcliffe (Livermore, UCRL-ID-115199, 1994).

Reprocessing removes nearly all of the fission products, greatly reducing the radiation field of the remaining weapon-usable transuranics. See Kang and von Hippel, "The limited non-proliferation benefits from recycling unseparated transuranics and rare-earth fission products from aged spent fuel," *Science & Global Security,* to be published.

The once-through fuel cycle leads to a continual buildup of the world's plutonium inventory that will not be as well "protected" by a high-radiation barrier after the fission products decay away.

however, the effort was halted, in large part because of US opposition. The United States questioned the motivation the countries had for acquiring these technologies and argued that its own example demonstrated that reprocessing is not required to have a robust nuclear-power program.

Balancing Benefits and Risks

Any decision to reprocess spent fuel in the United States must balance the potential benefits against the proliferation risks.

Fortunately, there is no near-term urgency to make a decision on implementing reprocessing in the United States. No foreseeable expansion of nuclear power in the US will make a qualitative change to the need for spent fuel storage over the next few decades. Even though Yucca Mountain may be delayed considerably, interim storage of spent fuel in dry casks, either at current reactor sites, or at a few regional facilities, or at a single national facility, is safe and affordable for a period of at least 50 years.[45]

Further, any spent fuel that would be emplaced at Yucca Mountain would remain available for reprocessing for many decades. Nuclear Regulatory Commission regulations require that the Yucca Mountain repository, if licensed, remain open and the waste be retrievable for 50 years after emplacement of the waste. In the meantime, the repository would provide excellent protection of spent fuel from terrorist threats, and would be capable of serving as a final disposal solution if that is eventually judged to be appropriate.

The decision on a second repository – or on whether to reprocess - can therefore be comfortably deferred, and should be deferred, for at least a decade. The deferral allows for time to determine the best path for the next phase of the expansion of nuclear power, and for the handling of the spent fuel from the nation's reactors.[46] It is important, however, to use that time effectively to explore the options more thoroughly than has been done to date.

In the longer term, the balance among the benefits, costs, and risks of reprocessing may change significantly. By reprocessing spent fuel and burning the recovered uranium and plutonium in a nuclear "breeder" reactor, it is possible to get as much as 50 times more energy out of the original uranium. Therefore, if nuclear energy expands substantially in the future and puts pressures on the availability of low-cost uranium fuel,[47] then reprocessing and breeder reactors could become the preferred option if the associated proliferation risks can be addressed.

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[45] *"Disposition of High-Level Waste & Spent Nuclear Fuel: Continuing Societal & Technical Challenges"*, NAS, 2001. There are important cost considerations as well. The costs of expanding Yucca Mountain or of developing a second repository are large, but the potential costs of a reprocessing program are likely to be larger. Not enough is known about any of these costs today to support a decision.

[46] NRC Commissioner Jeffrey Merrifield cautioned that new nuclear plants should be "evolutionary not revolutionary." NRC 17th Annual Regulatory Information Conference, March 8, 2005.

[47] This is unlikely to occur for at least a few decades: "The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel," M. Bunn, S. Fetter, J. P. Holdren & B. van der Zwaan, Nuclear Technology, Vol. 150, No. 3, June 2005.

Consequently, the AFCI research program should be maintained with an emphasis on enhancing both the proliferation resistance of the entire fuel cycle for each reactor-fuel-cycle concept being pursued and the technical support for new institutional arrangements for managing fuel cycle technology. By maintaining a program directed at fuel cycle research, the U.S. retains the ability to influence future directions, both technical and institutional, of the international community

Any reprocessing facility must be designed to be as proliferation-resistant as technically possible. At the same time, its operation must be sufficiently "transparent" that attempts to divert material or to operate it in a non-approved mode would quickly be detected by both the operators and multinational and international monitoring organizations. Several ideas for strengthening the proliferation resistance of such facilities are identified in a Report of the DOE's Nuclear Energy Research Advisory Committee "TOPS" report.[48]

If such fuel cycle R&D is to have impact worldwide, it will be necessary to have a global program, involving all of the advanced nuclear countries. It is particularly important to involve the other permanent members of the United Nations Security Council: the United Kingdom, France, Russia, and China. China should be included for the additional reason that its plans for nuclear-power development exceed the expansion plans of any other country.

The participation of Russia is also vital. Currently Russia is not included in the U.S.-led "Generation IV" international study on the future of nuclear power because of U.S. opposition to Russia's nuclear cooperation with Iran.[49]

In the short term, it is understandable that considerations relating to the immediate crisis over Iran's nuclear program should take precedence. However, the principal proliferation concern with Iran relates to centrifuges not associated with Russian cooperation and in the longer term, Russia cannot be left out of planning for a proliferation-resistant nuclear-energy future. Russia has enormous expertise in nuclear fuel-cycle technologies, is interested in marketing that expertise, and is the only country that is prepared to store spent fuel not only from countries to which it has supplied fresh fuel but also from third-party countries.[50]

In establishing any international fuel cycle R&D program, it is of overarching importance that the program itself not contribute to proliferation. This will require close collaboration between nuclear energy R&D and non-proliferation offices.

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[48] "Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems," Report by the TOPS Task Force of NERAC (October 2000).

[49] The US has refused to enter into the "Peaceful Uses of Atomic Energy" agreement with Russia as long as Russia cooperates with Iran.

[50] However, Russia has proposed this in the expectation that the spent fuel will eventually be reprocessed to provide startup cores for a new generation of fast-neutron breeder reactors.

Recommendations

- There is no urgent need for the US to initiate reprocessing or to develop additional national repositories. DOE programs should be aligned accordingly: shift Advanced Fuel Cycle Initiative R&D away from an objective of laying the basis for a near-term reprocessing decision; increase support for proliferation-resistance R&D and technical support for institutional measures for the entire fuel cycle.

- If fuel-cycle R&D is to have impact worldwide, and if proliferation resistance norms are to be integral, it will be necessary to have a global program, including all of the advanced nuclear countries. It is particularly important to involve the other permanent members of the United Nations Security Council: the United Kingdom, France, Russia, and China.

Appendix I:

Glossary of Terms

Actinide: an element with atomic number of 89 (actinium) or above.

Enriched uranium: Uranium in which the proportion of U-235 (to U-238) has been increased above the natural 0.7%. Reactor-grade uranium is usually enriched to about 3.5% U-235, weapons-grade uranium is more than 90% U-235.

Enrichment: Physical process of increasing the proportion of U-235 to U-238.

Fissile (of an isotope): Capable of capturing a slow (thermal) neutron and undergoing nuclear fission, e.g. U-235, U-233, Pu-239.

Fissionable (of an isotope): Capable of undergoing fission.

Fission: The splitting of a heavy nucleus into two, accompanied by the release of a relatively large amount of energy and usually one or more neutrons. It may be spontaneous but usually is due to a nucleus absorbing a neutron and becoming unstable.

Highly (or High)-enriched uranium (HEU): Uranium enriched to at least 20% U-235. (That in weapons is about 90% U-235.)

Low-enriched uranium: Uranium enriched to less than 20% U-235. (That in power reactors is usually 3.5 - 5.0% U-235.)

Reprocessing: Chemical treatment of spent reactor fuel to separate uranium and plutonium from the small quantity of fission product waste products and transuranic elements, leaving a much reduced quantity of high-level waste. (cf Waste, HLW).

Transuranic element: A very heavy element formed artificially by neutron capture and possibly subsequent beta decay(s). Has a higher atomic number than uranium (92). All are radioactive. Neptunium, plutonium, americium and curium are the best-known.

Uranium (U): A mildly radioactive element with two isotopes that are fissile (U-235 and U-233). Uranium is the basic fuel of nuclear energy.

Waste:
High-level waste (HLW) is highly radioactive material arising from nuclear fission. It can be recovered from reprocessing spent fuel, though some countries regard spent fuel itself as HLW. It requires very careful handling, storage and disposal.
Low-level waste (LLW) is mildly radioactive material usually disposed of by incineration and burial.

Appendix II

Authors, Reviewers & Process

The authors and reviewers have a broad range of expertise. Together, they have considerable expertise in safeguards, nuclear-fuel cycle technologies, nonproliferation policy, international cooperation on nonproliferation R&D, and the management of federal nuclear technology programs.

The authors drew on their own expertise as well as briefings on December 16 and 17 at the American Physical Society office in Washington DC. Participants at the briefings included the managers and directors of the relevant S&T proliferation-resistance programs in the Department of Energy's Office of Nuclear Science and Technology and National Nuclear Security Administration, and the State Department.

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www.aps.org/public_affairs/proliferation-resistance/biosT

BIOGRAPHY FOR ROGER HAGENGRUBER

Roger Hagengruber, Ph.D., is the Director of the Office for Policy, Security and Technology (OPS&T) and the Institute for Public Policy (IPP) and a Professor of Political Science at the University of New Mexico. He was formerly a Senior Vice President at Sandia National Laboratories. From 1991–99, he directed Sandia's primary mission in nuclear weapons during the transition following the end of the Cold War. He spent much of his 30-year career at Sandia in arms control and non-proliferation activities including several tours in Geneva as a negotiator. In recent years, he has focused on the nuclear transition in the former Soviet Union and in security issues associated with counter-terrorism and has chaired or served on numerous panels that have addressed these areas. He has traveled widely including many visits to Russia where he led the large interactive program between Sandia and the FSU.

His work at the University of New Mexico includes directing the IPP work in public survey including sampling of U.S. and European views on a wide range of security issues. The OPS&T is a relatively new function at UNM that creates multidisciplinary teams from labs and universities to execute projects that explore policy options in areas where security and technology are interrelated.

Dr. Hagengruber has a Ph.D. in experimental nuclear physics from the University of Wisconsin and is a graduate of the Industrial College of the Armed Forces. He has been associated with UNM since 1975.

Chairwoman BIGGERT. Thank you very much, Doctor.

Dr. Finck, you are recognized for five minutes.

STATEMENT OF DR. PHILLIP J. FINCK, DEPUTY ASSOCIATE LABORATORY DIRECTOR, APPLIED SCIENCE AND TECHNOLOGY AND NATIONAL SECURITY, ARGONNE NATIONAL LABORATORY

Dr. FINCK. Madame Chairwoman, Representative Honda, Members of the Subcommittee, it is my pleasure to be here today to testify on technical aspects of nuclear fuel reprocessing, and I have submitted a more detailed written statement for the record.

I am going to discuss how advanced nuclear fuel cycles can help mitigate the accumulation of spent nuclear fuel, and I will also describe the major options available and their respective advantages and disadvantages.

And I have brought two charts to help frame this discussion.

[Chart.]

The first chart that is on your right illustrates projected scenarios for the accumulation of spent nuclear fuel in the United States until the end of this century. Two limits to—related to the Yucca Mountain repository are important.

First is the legislative limit of 70,000 metric tons of spent nuclear fuel that will be reached around 2010.

Second is a technical limit of the repository's capacity of approximately 120,000 metric tons, which will be reached around 2030, assuming nuclear maintains its current market share. But if we can implement advanced fuel cycles rapidly enough, the amount of spent nuclear fuel could be systematically managed to remain below the Yucca Mountain technical limit, as indicated by the blue curve on the plot on the left.

The right-hand side of that chart illustrates also a key technical point for spent nuclear fuel. It is compromised primarily of uranium that, if separated from the fuel, can be disposed of as low-level waste or reused. The technical difficulties for disposal lie with the remaining elements that create short- and long-term heat loads and contribute to estimated doses at the boundary of the repository. In particular, it must be noted that the technical capacity of Yucca Mountain is limited by the very long-term heat generated by isotopes of plutonium, americium, and neptunium. To effectively manage repository space, these should be eliminated or significantly reduced. Reprocessing can separate these elements from the spent fuel, which makes it a first necessary step to eliminate them and must then be followed by recycle.

[Chart.]

The second chart on your left illustrates the three major options for managing spent nuclear fuel. The once-through cycle, that we are doing today in the United States, consists of sending the unprocessed spent fuel to the repository. Costs are fixed to one mill per kilowatt-hour, but the repository is not yet available. The mountain picture on the right illustrates how much repository space the United States needs to deal with the spent fuel.

Limited recycle is currently implemented in France and will soon be implemented in Japan. And that is the second picture. The spent fuel is reprocessed, and pure plutonium is separated and recycled as mixed-oxide fuel, partially burned in a commercial reactor and then stored or sent to disposal. The benefits to our repository would be quite limited, only an improvement of about 10 percent. This scheme as implemented today also raises the flag of proliferation risk. Claims that this scheme is overly expensive are not correct. The life cycle cost of limited recycle, using real actual French data, is only a few percent higher than that for the once-through option.

The last option, full recycle, is being researched intensely in the United States, France, Japan, and to some extent, in Russia. The U.S. approach relies on advanced technologies that significantly mitigate the disadvantages of the limited recycle option.

The first step, separations, could rely on the UREX+ technology that minimizes liquid waste streams, separates key elements in groups that are well suited for transmutation in different reactors. It offers a significant advantage for nonproliferation as we can effectively eliminate the risk of material diversion or facility misuse by developing advanced monitoring, modeling, and detection technologies, and integrating these technologies within the plant design. Also, consolidation of reprocessing facilities could be a key aspect for increasing proliferation resistance.

The second step consists of partially recycling plutonium, neptunium, and some other elements in thermal reactors. This step is not necessary, but may have an economic advantage that must be balanced with proliferation concerns.

The last step consists of closing the fuel cycle by transmuting all remaining elements in fast reactors using pyroprocessing separations technology, with enhanced proliferation resistance.

The full recycle option, as presented here, has major benefits.

It increases repository space utilization by a factor of more than 100 and delays the need for a second repository well into the next century. It eliminates all isotopes that are a proliferation concern. It allows adoption of modern separations and safeguards technologies that will greatly increase its proliferation resistance. The increase in life cycle costs is 10 percent or less according to OECD studies, and this must be contrasted with the significant benefits of this approach, particularly with regard to the cost and difficulties of a second repository.

To conclude, we believe that the technologies being considered today are mature enough to justify a down-selection by 2007 and the startup of an engineering-scale demonstration that could lead to large-scale commercialization. It is critical that the down-selection and demonstration be performed not only for reprocessing technologies but in concert with research in recycle technologies, including fast reactors.

Thank you, again, for the opportunity to testify before you on this timely and very important subject, and I would be pleased to answer any questions you might have.

[The prepared statement of Dr. Finck follows:]

PREPARED STATEMENT OF PHILLIP J. FINCK

SUMMARY

Management of spent nuclear fuel from commercial nuclear reactors can be addressed in a comprehensive, integrated manner to enable safe, emissions-free, nuclear electricity to make a sustained and growing contribution to the Nation's energy needs. Legislation limits the capacity of the Yucca Mountain repository to 70,000 metric tons from commercial spent fuel and DOE defense-related waste. It is estimated that this amount will be accumulated by approximately 2010 at current generation rates for spent nuclear fuel. To preserve nuclear energy as a significant part of our future energy generating capability, new technologies can be implemented that allow greater use of the repository space at Yucca Mountain. By processing spent nuclear fuel and recycling the hazardous radioactive materials, we can reduce the waste disposal requirements enough to delay the need for a second repository until the next century, even in a nuclear energy growth scenario. Recent studies indicate that such a closed fuel cycle may require only minimal increases in nuclear electricity costs, and are not a major factor in the economic competitiveness of nuclear power (the University of Chicago study, "The Economic Future of Nuclear Power," August 2004). However, the benefits of a closed fuel cycle can not be measured by economics alone; resource optimization and waste minimization are also important benefits. Moving forward in 2007 with an engineering-scale demonstration of an integrated system of proliferation-resistant, advanced separations and transmutation technologies would be an excellent first step in demonstrating all of the necessary technologies for a sustainable future for nuclear energy.

Nuclear Waste and Sustainability

World energy demand is increasing at a rapid pace. In order to satisfy the demand and protect the environment for future generations, energy sources must evolve from the current dominance of fossil fuels to a more balanced, sustainable approach. This new approach must be based on abundant, clean, and economical energy sources. Furthermore, because of the growing worldwide demand and competition for energy, the United States vitally needs to establish energy sources that allow for energy independence.

Nuclear energy is a carbon-free, secure, and reliable energy source for today and for the future. In addition to electricity production, nuclear energy has the promise to become a critical resource for process heat in the production of transportation fuels, such as hydrogen and synthetic fuels, and desalinated water. New nuclear plants are imperative to meet these vital needs.

To ensure a sustainable future for nuclear energy, several requirements must be met. These include safety and efficiency, proliferation resistance, sound nuclear materials management, and minimal environmental impacts. While some of these requirements are already being satisfied, the United States needs to adopt a more comprehensive approach to nuclear waste management. The environmental benefits of resource optimization and waste minimization for nuclear power must be pursued with targeted research and development to develop a successful integrated system with minimal economic impact. Alternative nuclear fuel cycle options that employ separations, transmutation, and refined disposal (e.g., conservation of geologic repository space) must be contrasted with the current planned approach of direct disposal, taking into account the complete set of potential benefits and penalties. In many ways, this is not unlike the premium homeowners pay to recycle municipal waste.

The spent nuclear fuel situation in the United States can be put in perspective with a few numbers. Currently, the country's 103 commercial nuclear reactors produce more than 2,000 metric tons of spent nuclear fuel per year (masses are measured in heavy metal content of the fuel, including uranium and heavier elements). The Yucca Mountain repository has a legislative capacity of 70,000 metric tons, including spent nuclear fuel and DOE defense-related wastes. By approximately 2010 the accumulated spent nuclear fuel generated by these reactors and the defense-related waste will meet this capacity, even before the repository starts accepting any spent nuclear fuel. The ultimate technical capacity of Yucca Mountain is expected to be around 120,000 metric tons, using the current understanding of the Yucca Mountain site geologic and hydrologic characteristics. This limit will be reached by including the spent fuel from current reactors operating over their lifetime. Assuming nuclear growth at a rate of 1.8 percent per year after 2010, the 120,000 metric ton capacity will be reached around 2030. At that projected nuclear growth rate, the U.S. will need up to nine Yucca Mountain-type repositories by the end of this century. Until Yucca Mountain starts accepting waste, spent nuclear fuel must be stored in temporary facilities, either storage pools or above ground storage casks.

Today, many consider repository space a scarce resource that should be managed as such. While disposal costs in a geologic repository are currently quite affordable for U.S. electric utilities, accounting for only a few percent of the total cost of electricity, the availability of U.S. repository space will likely remain limited.

Only three options are available for the disposal of accumulating spent nuclear fuel:

- Build more ultimate disposal sites like Yucca Mountain.
- Use interim storage technologies as a temporary solution.
- Develop and implement advanced fuel cycles, consisting of separations technologies that separate the constituents of spent nuclear fuel into elemental streams, and transmutation technologies that destroy selected elements and greatly reduce repository needs.

A responsible approach to using nuclear power must always consider its whole life cycle, including final disposal. We consider that temporary solutions, while useful as a stockpile management tool, can never be considered as ultimate solutions. It seems prudent that the U.S. always have at least one set of technologies available to avoid expanding geologic disposal sites.

Spent Nuclear Fuel

The composition of spent nuclear fuel poses specific problems that make its ultimate disposal challenging. Fresh nuclear fuel is composed of uranium dioxide (about 96 percent U238, and four percent U235). During irradiation, most of the U235 is fissioned, and a small fraction of the U238 is transmuted into heavier elements (known as "transuranics"). The spent nuclear fuel contains about 93 percent uranium (mostly U238), about one percent plutonium, less than one percent minor actinides (neptunium, americium, and curium), and five percent fission products. Uranium, if separated from the other elements, is relatively benign, and could be disposed of as low-level waste or stored for later use. Some of the other elements raise significant concerns:

- The fissile isotopes of plutonium, americium, and neptunium are potentially usable in weapons and, therefore, raise proliferation concerns. Because spent nuclear fuel is protected from theft for about one hundred years by its intense radioactivity, it is difficult to separate these isotopes without remote handling facilities.
- Three isotopes, which are linked through a decay process (Pu241, Am241, and Np237), are the major contributors to the estimated dose for releases from the repository, typically occurring between 100,000 and one million years, and also to the long-term heat generation that limits the amount of waste that can be placed in the repository.
- Certain fission products (cesium, strontium) are major contributors to the repository's short-term heat load, but their effects can be mitigated by providing better ventilation to the repository or by providing a cooling-off period before placing them in the repository.
- Other fission products (Tc99 and I129) also contribute to the estimated dose.

The time scales required to mitigate these concerns are daunting: several of the isotopes of concern will not decay to safe levels for hundreds of thousands of years. Thus, the solutions to long-term disposal of spent nuclear fuel are limited to three options: the search for a geologic environment that will remain stable for that period; the search for waste forms that can contain these elements for that period; or the destruction of these isotopes. These three options underlie the major fuel cycle strategies that are currently being developed and deployed in the U.S. and other countries.

Options for Disposing of Spent Nuclear Fuel

Three options are being considered for disposing of spent nuclear fuel: the once-through cycle is the U.S. reference; limited recycle has been implemented in France and elsewhere and is being deployed in Japan; and full recycle (also known as the closed fuel cycle) is being researched in the U.S., France, Japan, and elsewhere.

1. Once-through Fuel Cycle

This is the U.S. reference option where spent nuclear fuel is sent to the geologic repository that must contain the constituents of the spent nuclear fuel for hundreds of thousands of years. Several countries have programs to develop these repositories, with the U.S. having the most advanced program. This approach is considered safe, provided suitable repository locations and space can be found. It should be noted that other ultimate disposal options have been researched (e.g., deep sea disposal; boreholes and disposal in the sun) and abandoned. The challenges of long-term geologic disposal of spent nuclear fuel are well recognized, and are related to the uncertainty about both the long-term behavior of spent nuclear fuel and the geologic media in which it is placed.

2. Limited Recycle

Limited recycle options are commercially available in France, Japan, and the United Kingdom. They use the PUREX process, which separates uranium and plutonium, and directs the remaining transuranics to vitrified waste, along with all the fission products. The uranium is stored for eventual reuse. The plutonium is used to fabricate mixed-oxide fuel that can be used in conventional reactors. Spent mixed-oxide fuel is currently not reprocessed, though the feasibility of mixed-oxide reprocessing has been demonstrated. It is typically stored or eventually sent to a geologic repository for disposal. Note that a reactor partially loaded with mixed-oxide fuel can destroy as much plutonium as it creates. Nevertheless, this approach always results in increased production of americium, a key contributor to the heat generation in a repository. This approach has two significant advantages:

- It can help manage the accumulation of plutonium.
- It can help significantly reduce the volume of spent nuclear fuel (the French examples indicate that volume decreases by a factor of four).

Several disadvantages have been noted:

- It results in a small economic penalty by increasing the net cost of electricity a few percent.
- The separation of pure plutonium in the PUREX process is considered by some to be a proliferation risk; when mixed-oxide use is insufficient, this material is stored for future use as fuel.
- This process does not significantly improve the use of the repository space (the improvement is around 10 percent, as compared to a factor of 100 for closed fuel cycles).
- This process does not significantly improve the use of natural uranium (the improvement is around 15 percent, as compared to a factor of 100 for closed fuel cycles).

3. Full Recycle (the Closed Fuel Cycle)

Full recycle approaches are being researched in France, Japan, and the United States. This approach typically comprises three successive steps: an advanced separations step based on the UREX+ technology that mitigates the perceived disadvantages of PUREX, partial recycle in conventional reactors, and closure of the fuel cycle in fast reactors.

The first step, UREX+ technology, allows for the separations and subsequent management of highly pure product streams. These streams are:

- Uranium, which can be stored for future use or disposed of as low-level waste.
- A mixture of plutonium and neptunium, which is intended for partial recycle in conventional reactors followed by recycle in fast reactors.
- Separated fission products intended for short-term storage, possibly for transmutation, and for long-term storage in specialized waste forms.

- The minor actinides (americium and curium) for transmutation in fast reactors.

The UREX+ approach has several advantages:

- It produces minimal liquid waste forms, and eliminates the issue of the "waste tank farms."
- Through advanced monitoring, simulation and modeling, it provides significant opportunities to detect misuse and diversion of weapons-usable materials.
- It provides the opportunity for significant cost reduction.
- Finally and most importantly, it provides the critical first step in managing all hazardous elements present in the spent nuclear fuel.

The second step—partial recycle in conventional reactors—can expand the opportunities offered by the conventional mixed-oxide approach. In particular, it is expected that with significant R&D effort, new fuel forms can be developed that burn up to 50 percent of the plutonium and neptunium present in spent nuclear fuel. (Note that some studies also suggest that it might be possible to recycle fuel in these reactors many times—i.e., reprocess and recycle the irradiated advanced fuel—and further destroy plutonium and neptunium; other studies also suggest possibilities for transmuting americium in these reactors. Nevertheless, the practicality of these schemes is not yet established and requires additional scientific and engineering research.) The advantage of the second step is that it reduces the overall cost of the closed fuel cycle by burning plutonium in conventional reactors, thereby reducing the number of fast reactors needed to complete the transmutation mission of minimizing hazardous waste. This step can be entirely bypassed, and all transmutation performed in advanced fast reactors, if recycle in conventional reactors is judged to be undesirable.

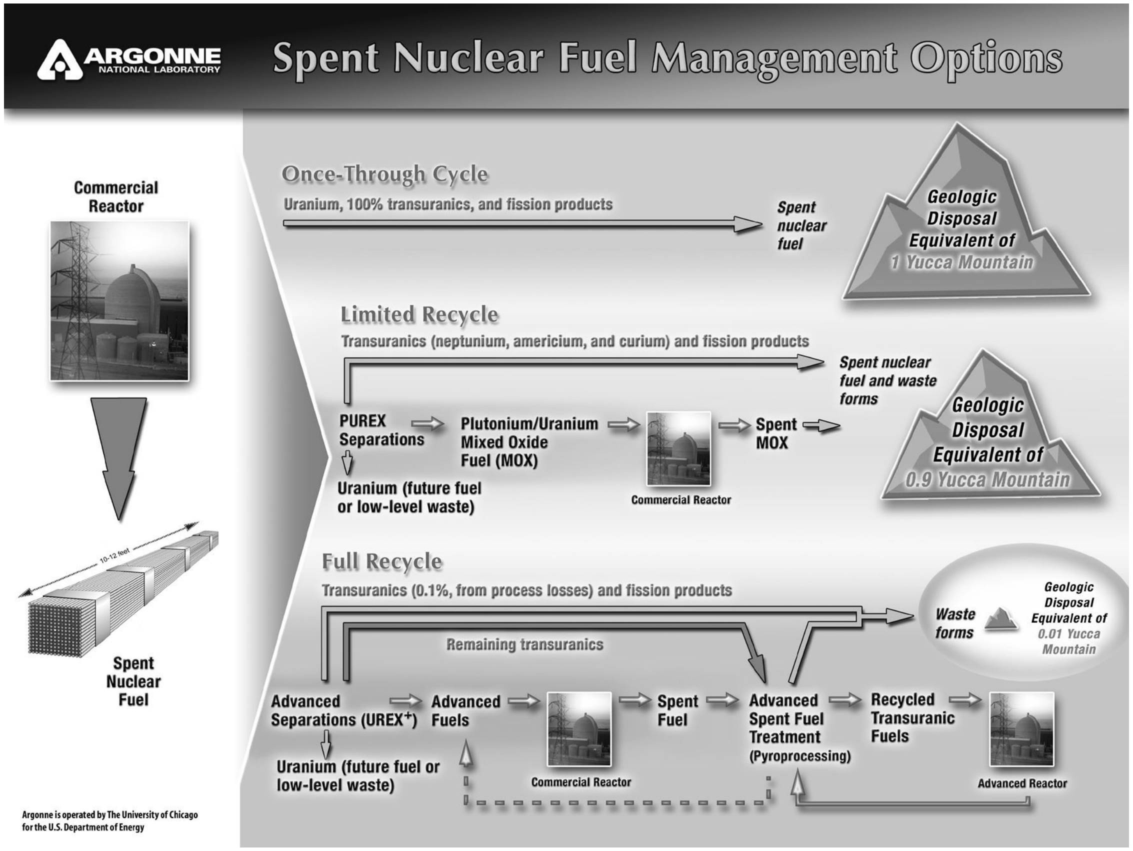
The third step, closure of the fuel cycle using fast reactors to transmute the fuel constituents into much less hazardous elements, and pyroprocessing technologies to recycle the fast reactor fuel, constitutes the ultimate step in reaching sustainable nuclear energy. This process will effectively destroy the transuranic elements, resulting in waste forms that contain only a very small fraction of the transuranics (less than one percent) and all fission products. These technologies are being developed at Argonne National Laboratory and Idaho National Laboratory, with parallel development in Japan, France, and Russia.

The full recycle approach has significant benefits:

- It can effectively increase use of repository space by a factor of more than 100.
- It can effectively increase the use of natural uranium by a factor of 100.
- It eliminates the uncontrolled buildup of all isotopes that are a proliferation risk.
- The fast reactors and the processing plant can be deployed in small co-located facilities that minimize the risk of material diversion during transportation.
- The fast reactor does not require the use of very pure weapons usable materials, thus increasing their proliferation resistance.
- It finally can usher the way towards full sustainability to prepare for a time when uranium supplies will become increasingly difficult to ensure.
- These processes would have limited economic impact; the increase in the cost of electricity would be less than 10 percent (ref: OECD).
- Assuming that demonstrations of these processes are started by 2007, commercial operations are possible starting in 2025; this will require adequate funding for demonstrating the separations, recycle, and reactor technologies.
- The systems can be designed and implemented to ensure that the mass of accumulated spent nuclear fuel in the U.S. would always remain below 100,000 metric tons—less than the technical capacity of Yucca Mountain—thus delaying, or even avoiding, the need for a second repository in the U.S.

Conclusion

A well engineered recycling program for spent nuclear fuel will provide the United States with a long-term, affordable, carbon-free energy source with low environmental impact. This new paradigm for nuclear power will allow us to manage nuclear waste and reduce proliferation risks while creating a sustainable energy supply. It is possible that the cost of recycling will be slightly higher than direct disposal of spent nuclear fuel, but the Nation will only need one geologic repository for the ultimate disposal of the residual waste.



Spent Nuclear Fuel Management Options

ARGONNE NATIONAL LABORATORY

Commercial Reactor

Spent Nuclear Fuel

Once-Through Cycle

Uranium, 100% transuranics, and fission products

Spent nuclear fuel

Geologic Disposal Equivalent of 1 Yucca Mountain

Limited Recycle

Transuranics (neptunium, americium, and curium) and fission products

PUREX Separations → Plutonium/Uranium Mixed Oxide Fuel (MOX) → Commercial Reactor → Spent MOX

Uranium (future fuel or low-level waste)

Spent nuclear fuel and waste forms

Geologic Disposal Equivalent of 0.9 Yucca Mountain

Full Recycle

Transuranics (0.1%, from process losses) and fission products

Remaining transuranics

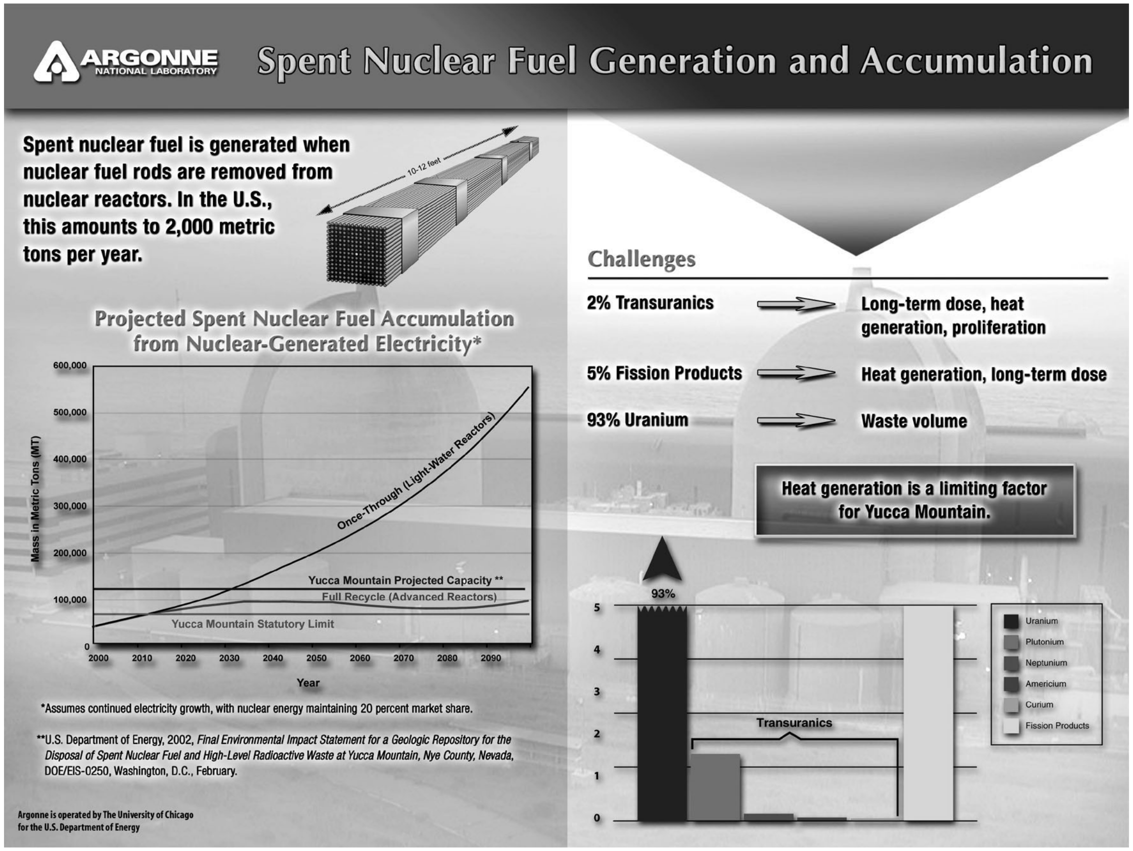
Advanced Separations (UREX$^+$) → Advanced Fuels → Commercial Reactor → Spent Fuel → Advanced Spent Fuel Treatment (Pyroprocessing) → Recycled Transuranic Fuels → Advanced Reactor

Uranium (future fuel or low-level waste)

Waste forms

Geologic Disposal Equivalent of 0.01 Yucca Mountain

Argonne is operated by The University of Chicago for the U.S. Department of Energy



Spent Nuclear Fuel Generation and Accumulation

Spent nuclear fuel is generated when nuclear fuel rods are removed from nuclear reactors. In the U.S., this amounts to 2,000 metric tons per year.

Projected Spent Nuclear Fuel Accumulation from Nuclear-Generated Electricity*

*Assumes continued electricity growth, with nuclear energy maintaining 20 percent market share.

**U.S. Department of Energy, 2002, *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, DOE/EIS-0250, Washington, D.C., February.

Argonne is operated by The University of Chicago for the U.S. Department of Energy

Challenges

2% Transuranics → **Long-term dose, heat generation, proliferation**

5% Fission Products → **Heat generation, long-term dose**

93% Uranium → **Waste volume**

Heat generation is a limiting factor for Yucca Mountain.

APPENDIX 1:

Reprocessing Technologies

There are currently three mature options to reprocess spent nuclear fuel.

PUREX—Is the most common liquid-liquid extraction process for treatment of light water reactor spent fuel. The irradiated fuel is dissolved in nitric acid, and uranium and plutonium are extracted in the organic phase by an organic solvent consisting of tributyl phosphate in kerosene, while the fission products remain in the aqueous nitric phase. Further process steps enable the subsequent separation of uranium from plutonium.

Advantages—fully commercialized process, with over 50 years of experience.

Disadvantage—it is not efficient enough to achieve the present requirements for separations of technetium, cesium, strontium, neptunium, americium and curium.

UREX+—Is an advanced liquid-liquid extraction process for treatment of light water reactor spent fuel. Similar to PUREX, the irradiated fuel is dissolved in nitric acid. The UREX+ process consists of a series of solvent-extraction steps for the recovery of Pu/Np, Tc, U, Cs/Sr, Am and Cm.

Advantages—meets current separations requirements for continuous recycle. Builds on engineering experience derived from current aqueous reprocessing facilities such as La Hague.

Disadvantage—can not directly process short-cooled and some specialty fuels being designed for advanced reactors.

Pyroprocessing—These technologies rely on electrochemical processes rather than chemical extraction processes to achieve the desired degree of conversion or purification of the spent fuel. If oxide fuel is processed, it is converted to metal after the irradiated fuel is disassembled. The metallic fuel is then treated to separate uranium and the transuranic elements from the fission product elements.

Advantages—ability to process short-cooled and specialty fuels being designed for advanced reactors.

Disadvantages—does not meet current separations requirements for continuous recycle in thermal reactors, but ideal for fast spectrum reactors.

APPENDIX 2:

Answers to Specific Questions

1. What are the advantages and disadvantages of using reprocessing to address efficiency of fuel use, waste management and non-proliferation? How would you assess the advantages and disadvantages, and how might the disadvantages be mitigated?

Reprocessing of spent fuel is a necessary step in an advanced fuel cycle, but is insufficient to yield any significant benefits by itself: benefits are only incurred once the reprocessed materials are recycled and partially or totally eliminated. Two types of recycle schemes are typically considered: limited recycle in conventional reactors, and full recycle in advanced reactors.

Limited Recycle

Limited recycle options are commercially available in France, Japan, and the United Kingdom. They utilize the PUREX process, which separates uranium and plutonium, and directs the remaining transuranics to vitrified waste, along with all the fission products. The uranium is stored for eventual reuse. The plutonium is used to fabricate mixed oxide (MOX) fuel that can be used in conventional reactors. Spent MOX fuel is currently not reprocessed (though feasibility of MOX reprocessing has been demonstrated) and is typically stored or eventually sent to a geologic repository for disposal. Note that a reactor partially loaded with MOX fuel can destroy as much plutonium as it creates. Nevertheless, this approach always results in an increase in the production of americium (a key contributor to the heat generation in a repository). This approach has several advantages:

- It can help manage the accumulation of plutonium.
- It can help significantly reduce the volume of spent nuclear fuel (SNF) (the French examples indicates a volume decrease by a factor of four).

Several disadvantages have been noted:

- It results in a small economic penalty, as the increase in the net cost of electricity is a few percent.
- The separation of pure plutonium in the PUREX process is considered by some to be a proliferation risk; when MOX utilization is insufficient, this material is stored for future use as fuel.
- This process does not significantly improve the utilization of the repository space (the improvement is around 10 percent, as compared to a factor of 100 for closed fuel cycles).
- This process does not significantly improve the utilization of natural uranium (the improvement is around 15 percent, as compared to a factor of 100 for closed fuel cycles).

Full Recycle (the Closed Fuel Cycle)

Full recycle approaches are being researched in France, Japan, and the United States. This approach is typically comprised of three successive steps: an advanced separations step based on the UREX+ technology that mitigates the perceived disadvantages of PUREX, partial recycle in conventional reactors, and closure of the fuel cycle in fast reactors.

The first step, UREX+ technology, allows for the separations and subsequent management of very pure streams of products. It produces the following streams of products: uranium, that can be stored for future use or can be disposed of as low-level waste; a mixture of plutonium and neptunium that are intended for partial recycle in conventional reactors followed by recycle in fast reactors; separated fission products intended for short-term storage, possibly for transmutation, and for long-term storage in specialized waste forms; and the minor actinides (americium and curium) for transmutation in fast reactors. The UREX+ approach has several advantages: it produces minimal liquid waste forms (and eliminates the issue of the "waste tank farms"); through advanced monitoring, simulation and modeling it provides significant opportunities for detecting misuse and diversion of weapons usable materials; it provides the opportunity for significant cost reduction; and, finally and most importantly, it provides the critical first step in managing all hazardous elements present in the SNF.

The second step, partial recycle in conventional reactors can expand the opportunities offered by the conventional MOX approach. In particular, it is expected that with significant R&D effort, new fuel forms can be developed that can burn up to 50 percent of the plutonium and neptunium present in the SNF. (Note that some studies also suggest that it might be possible to recycle fuel in these reactors multiple times (i.e., reprocess and recycle the irradiated advanced fuel) and further destroy plutonium and neptunium; other studies also suggest possibilities for transmuting americium in these reactors. Nevertheless, the practicality of these schemes is not yet established and requires additional scientific and engineering research.) The advantage of the second step is that it reduces the overall cost of the closed fuel cycle by burning plutonium in conventional reactors, and reducing the number of fast reactors needed to complete the transmutation mission of minimizing hazardous waste. This step can be entirely bypassed, and all transmutation performed in advanced fast reactors, if recycle in conventional reactors is judged to be undesirable.

The third step, closure of the fuel cycle, using fast reactors to transmute the fuel constituents into much less hazardous elements, and pyroprocessing technologies to recycle the fast reactor fuel, constitutes the ultimate step in reaching sustainability for nuclear energy. This process will effectively destroy the transuranic elements, resulting in waste forms that contain only a very small fraction of the transuranics (less than one percent) and all fission products. These technologies are being developed at Argonne National Laboratory and Idaho National Laboratory, with parallel development in Japan, France, and Russia.

The full recycle approach has significant benefits:

— It can effectively increase the utilization of the repository space by a factor in excess of 100.

— It can effectively increase the utilization of natural uranium by a factor of 100.

— It eliminates the uncontrolled buildup of all isotopes that are a proliferation risk.

— The fast reactors and the processing plant can be deployed in small co-located facilities that minimize the risk of material diversion during transportation.

— The fast reactor does not require the use of very pure weapons usable materials, thus increasing their proliferation resistance.

— It finally can usher the way towards full sustainability to prepare for a time when uranium supplies will become increasingly difficult to ensure.

— These processes would have limited economic impact: the increase in the cost of electricity would be less than 10 percent (ref: OECD).

— Assuming that demonstration of these processes is started by 2007, commercial operations are possible starting in 2025; this will require adequate funding for demonstrating the separations, recycle, and reactor technologies.

— The systems can be designed and implemented to ensure that the mass of accumulated SNF in the U.S. would always remain below 100,000MT, (Note: less than the technical capacity of Yucca Mountain) thus delaying, or even avoiding, the need for a second repository in the U.S.

Several disadvantages have been noted:

— These processes would have limited economic impact: the increase in the cost of electricity would be less than 10 percent (ref: OECD).

— Management of potentially weapons-usable materials may be viewed as a proliferation risk.

These disadvantages can be addressed by specific actions:

— Fuel cycle and reactor R&D is currently going on in the DOE Advanced Fuel Cycle Initiative (AFCI) and Gen-IV programs to reduce the costs of processing, fuel fabrication, and advanced reactors.

— Advanced simulation, modeling, and detection techniques can be used in fuel cycle facilities to improve material accountability and decrease the risk of misuse or diversion.

— An aggressive development and demonstration program of the advanced reactors and recycling options is needed to allow commercialization in a reasonable timeframe.

2. What are the greatest technological hurdles in developing and commercializing advanced reprocessing technologies? Is it possible for the government to select a technology by 2007?

To answer the first part of the question, the first major hurdle is the current inability to test the chemical processing steps at a pilot-scale using spent nuclear fuel (both as individual process steps and in an integrated manner simulating plant operations) to verify that both the process itself and the larger scale equipment will function as intended, and to minimize the technical risks in designing the commercial-scale plant. The processing methods currently being refined under the scope of the DOE AFCI program are being designed to very high standards for purity of products and efficiency of recovery, in order to reduce costs and minimize the hazardous content of high-level wastes. The processes have been successfully tested at laboratory scale (about one-millionth of industrial scale). Normal expectations for scale-up of industrial chemical processes are that the processes proven in the laboratory will perform well at full scale, provided that the process and equipment function as intended. In order to test process operations and equipment designs, it is necessary to conduct pilot plant operations at one/one-hundredth to one/one-thousandth of industrial scale with the complete process.

The second major hurdle is related to the first, in that there is an insufficient supply of some of the various chemical elements needed for the development and testing of product storage forms and waste disposal forms. However, it is anticipated that these would become available as a result of pilot-scale testing, but the lack of materials will hinder progress prior to that time.

For the second part of the question, yes, it is completely reasonable to select a processing technology by 2007, given the present state of development for the processing technologies. The level of success achieved in the DOE AFCI program to date indicates that the development of at least one processing technology satisfying program goals, UREX+, will be advanced to the stage where pilot-scale testing is warranted. At that time, it should also be possible to evaluate whether any of the other promising technologies currently being studied have proven capable of meeting program goals, and are also near to pilot-scale testing.

However, it must be emphasized that the reprocessing technology by itself will not provide any significant benefits unless the development of such capability is matched by similar advances in recycling technologies. In the case of full recycle, the development of both suitable reactors for recycling transuranics and appropriate nuclear fuel forms containing transuranics must proceed in parallel to testing and implementation of spent fuel processing. Only with all of the pieces in place will substantial benefits be achievable.

3. What reprocessing technologies currently are being developed at Argonne or at other national labs? What technical questions must be answered?

AFCI processing (chemical separations) technology is being developed at Argonne National Laboratory, Idaho National Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, Sandia National Laboratory, and Savannah River National Laboratory. All are involved with the development of aqueous solvent extraction technologies (the suite of UREX+ processes), while ANL and INL are also developing the pyrochemical processing technology that will be required for the nuclear fuel cycle associated with Gen-IV reactors. The aqueous technology is needed for near-term application, and the emphasis is on process optimization, equipment development, and plant design. The pyrochemical technology is needed for deployment of the Gen-IV reactors, and requires large scale demonstration. Emphasis on pyroprocessing is in testing of process features, with some work in progress on process equipment and facility design.

The UREX+ solvent extraction demonstrations have shown that it can meet separations criteria; however, integrated, engineering-scale testing is required to complete development. Continuing work is required to optimize flowsheets and increase process robustness and operations efficiency. An adequate facility is required for engineering-scale demonstrations to test equipment, advanced instrumentation for process control and PR&PP (Proliferation Resistance and Physical Protection), conversion of product and waste forms.

Pyroprocessing requires continued process development followed by engineering-scale demonstration of flowsheets developed for reprocessing the many alternative advanced reactor fuels. Improvements in the areas of transuranic element recovery and process equipment design needs to be completed. Similar to the UREX+ process an adequate facility is required for engineering-scale demonstration.

4. What reprocessing technologies are still in the basic research stage, what advantages might they offer, and what is the estimated timeline for development of laboratory scale models?

There are currently two mature technologies for reprocessing, UREX+ and pyroprocessing. For industrial scale implementation optimization of these technologies is still necessary:

- Off-gas treatment from fuel decladding and dissolution for retention of tritium, carbon-14, ruthenium, and technetium to prevent their migration to downstream operations where they are harder to sequester. Development of high efficiency scrubbers is currently an effort in other countries.
- Advanced instrumentation and process-sampling techniques for near real time accounting for process control and material accountability.
- Process diagnostics for early on-line detection using signals from process instrumentation to differentiate legitimate process operation versus clandestine product diversion.
- Waste forms optimization for preventing migration of radionuclides and reduce potential heath hazard to the public.

Nevertheless, there are a number of novel technologies where basic research could provide an alternative to the current technologies, with the potential of minimizing dose to the public and workers and environmental impacts. These research areas are:

- Development of ligands, chelating agents, and advanced extractant molecules based on fundamental principles to guide their preparation. Advantages—molecules could be tailored to perform a specific function such as separations of a given transuranic element. Estimated timeline 20 years.
- Development of environmentally benign separations processes such as based on magnetic and electronic differences. Advantages—produce minimum secondary wastes and significantly decrease the consumption of chemicals. Estimated timeline 30 years.
- Development of bio-based separations. Advantages—identify methods and replicate biological compound functions leading to new separation schemes, for example, separations of actinides over lanthanides. Estimated timeline 50 years.

5. How would you contrast what is being done internationally with U.S. plans for reprocessing, recycling and associated waste management? What countries recycle now? What components of the waste fuel are or can be used to make new reactor fuel?

Commercial reprocessing plants in France, the United Kingdom and Japan utilize the PUREX process, which separates uranium and plutonium and directs the remaining transuranics (americium, neptunium, and curium) to vitrified waste along with all of the fission products. Reprocessing operations in the U.K. may be terminated within the next 10 years, primarily because the shutdown of gas-cooled power reactors is limiting the need for the Sellafield B–205 plant. BNFL's THORP plant at Sellafield is principally used for light water reactor (LWR) spent fuel processing; the U.K. has only one LWR in operation and the market for foreign LWR fuel processing is decreasing. A shutdown of THORP has been announced for 2010. In contrast, a vigorous reprocessing activity is in progress in France at the La Hague plant of COGEMA. This plant is processing spent fuel from foreign sources as well as from the 57 power reactors of Electricité de France. Plutonium is recovered for recycle to the EdF reactors as mixed oxide (MOX) fuel. Research on means for improving waste management through reprocessing have been stimulated by the 1991 law, and research is in progress now at the laboratories of the Commissariat à l'Energie Atomique (CEA) that is following much the same lines as that pioneered in the AFCI program of DOE. Commercial reprocessing will begin soon in Japan at the Rokkasho-mura plant of Japan Nuclear Fuel Ltd. The Rokkasho Reprocessing Plant is designed for the production of a mixed uranium-plutonium product that can be used to produce mixed oxide fuel for recycle in Japanese light water reactors. Japanese laboratories are also experimenting with advanced spent fuel processing methods.

The U.S. program represents a transition to an advanced nuclear fuel cycle. In the U.S., emphasis is being placed on technologies that can be successfully deployed in the next 20 years or so and be economically competitive as well as secure against all threats. The wastes arising from future U.S. process plants will be virtually free of radiotoxic elements, and there will be no generation of liquid wastes requiring underground tank storage. We expect our efforts to help us regain international leadership in the field of nuclear energy.

Both Japan and France are currently developing advanced fuel cycles, similar to the ones described in this paper, where there first would be partial recycle in conventional reactors, followed by closure of the fuel cycle in fast reactors. The U.S. program has had significant international collaborations with these two countries, and there have been excellent exchanges of research results. The approaches in the three countries are relatively well aligned, with a stronger emphasis on the short-term development of separations technologies in the U.S., and a stronger emphasis on the long-term development of fast reactors in France and Japan.

BIOGRAPHY FOR PHILLIP J. FINCK

Phillip Finck received his Ph.D. in Nuclear Engineering from MIT in 1982, and a MBA in 2001 from the University of Chicago. He was a mechanical engineer at NOVATOME, France from 1983 to 1986, and was involved in the safety and design of fast reactors, including Superphenix. In 1986, he joined Argonne National Laboratory and was involved in neutronics methods development for the Integral Fast Reactor concept, and later for the New Production Reactor. In 1991, he became the lead for EBR–II neutronics analyses at ANL–E. In 1993 he joined the French Atomic Energy Commission where he became the head of the Reactor Physics Laboratory at the Cadarache Center, with activities in LWR and LMR physics, criticality safety, fuel cycle physics, and nuclear data. In 1995, he was elected to chair the European nuclear data project—JEF. Dr. Finck rejoined ANL in 1997, where he became the Associate Director of the Technology Development Division. He has led the ANL activities in the Advanced Accelerator Applications program since 2000, and has been heavily involved in transforming the program from accelerator-based to reactor-based transmutation. In 2003 he was named Deputy Associate Laboratory Director, Engineering Research, where he was responsible for coordination of all nuclear energy related activities at ANL, including AFCI and Gen-IV programs, and development of new initiatives. Since 2004, Dr. Finck is the Deputy Associate Laboratory Director for Applied Science and Technology and National Security; in this position, he coordinates all energy-related activities at ANL.

Dr. Finck is a Fellow of the American Nuclear Society.

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June 13, 2005

Representative Judy Biggert
Chairwoman, Energy Subcommittee
House Committee on Science
Suite 2320, Rayburn House Office Building
Washington DC, 20515-6301

Dear Representative Biggert:

This is to provide a record of financial disclosure according to the Rules of the House of Representatives for testimony at your Subcommittee on Energy Hearing titled "Nuclear Fuel Reprocessing" on June 16, 2005.

I am supported by Argonne National Laboratory under a Management and Operating Contract (No. W3-109-ENG-38) between the U.S. Department of Energy and the University of Chicago.

Please let me know if you require any further information.

Sincerely,

P Finck

Phillip J. Finck
Deputy Associate Laboratory Director
Applied Science and Technology
and National Security

PJF/ds

Operated by The University of Chicago for The United States Department of Energy

DISCUSSION

Chairwoman BIGGERT. Thank you very much for your testimony.

We will now turn to the questions, and I will yield five minutes to the—Chairman Hobson.

Mr. HOBSON. I just have, quickly, a couple of things, because I have to leave, but I want to thank you all for your testimony. I may not agree with all of it, but I like it. I like the fact that we are having this dialogue, because it wasn't happening.

Mr. Bunn, I would like to ask you, in your numbers that you have put together, do you include any costs associated to the liability increase each year that this government has to pay the utilities for not removing the waste from their site?

Mr. BUNN. We include—one of the assumptions that we make that is favorable to reprocessing, we tried to make assumptions, in general, that were favorable to reprocessing in order to be, you know, fair and ironclad in our conclusions. And we assigned to the cost of the direct disposal option 100 percent of the cost of interim storage for many decades prior to disposal, and we assumed that there was zero cost for interim storage with respect—on the reprocessing side. So yes, we did include that. And the costs of storage are actually——

Mr. HOBSON. Oh, no, no, no. I am talking about the liability——

Mr. BUNN. I understand that, but the liability——

Mr. HOBSON.—cost. There is $500 million——

Mr. BUNN. The liability to the government depends on the costs to store that fuel. The—if the government takes title to that fuel and pays for its storage, then its liability is the——

Mr. HOBSON. No, but you are making an assumption that would take legislation, as I understand it, to do. Is that correct?

Mr. BUNN. I am saying that the government should not be in the business of paying the utilities amounts that far exceed their actual cost for storing the amount of nuclear fuel, and therefore, one should look at what the cost of storing spent fuel actually is. The cost of providing 40 years of dry cask storage for spent fuel is less than $200 a kilogram. The cost of reprocessing spent nuclear fuel, even in a new facility, financed entirely with government money at a low government rate of interest, would be more than $1,000 a kilogram if its capital and operating costs were identical to the costs of the plants built in France and Britain, and much more than that if it were identical to the cost of the most recent plant built in Japan, whose costs are astronomical.

So it is really—it is quite a large difference. You will find, if you talk to utilities, that none of them are particularly interested in paying for reprocessing of their spent fuel if they can simply buy dry casks.

Mr. HOBSON. Well, a lot of them are trying to move them out of the area that they have got them in, so——

Mr. BUNN. Yes, they would love to have the government take it away. There is no doubt about that.

Mr. HOBSON. No. No. Excuse me. They are providing a site in Utah—they are attempting to provide a site in Utah, because they want to move them——

Mr. BUNN. That is right.

Mr. HOBSON.—out of the cities where they have got them.

Mr. BUNN. Right.

Mr. HOBSON. And the security problems that they have, which I am suspect of the—let me put it this way. I am suspect of the numbers, but we will look at the numbers.

I would also like to ask you, have you visited the sites in France?

Mr. BUNN. I have.

Mr. HOBSON. And have you written the same negative situation with the sites in France and encouraged them to do away with their sites and get away from reprocessing? Because if you look where those sites are, there are vineyards growing up. And if you go to the Netherlands, there is a playground on the other side. Obviously, there are differing opinions in the world, and I am always interested how we always write about our side of it, but we have not written—maybe you have, and I don't know the answer. You should never ask a question you don't know the answer to, but I am concerned that I don't see the same concerns expressed about these existing facilities, which what I have seen, seem to try to do it in a responsible way, and have—don't have the reliance upon fossil fuels in their country that we do, don't have the proliferation of the air that we do from the plants. And my point is, we need to move forward in this, but I don't see the same negatives written about that that is written about our ability to try to sustain our country. So I will let you answer that, and then I will——

Mr. BUNN. Well, first of all, I am not against nuclear energy. I am a supporter of nuclear energy, and as I made the point at the end of my testimony, I believe that if—those who support nuclear energy ought to be trying to make it as cheap, as simple, as safe, and as non-controversial as possible in order to build the support needed to grow nuclear energy. And I think that reprocessing with traditional PUREX type technologies, as implemented in France and Britain and Japan, points in the wrong direction on every count. I have expressed concern about the facilities in France and Britain and Japan for many years, as have many of my colleagues. But the reality is those facilities exist. Large investments have been made. Those countries are not going to change their process—their approaches any time soon. However, it is worth noting that when those facilities were first built, they had substantial foreign customers, and now the foreign customer base is dwindling away to almost nothing, because utilities around the world are realizing increasingly that dry cask storage offers a cheaper alternative, which leaves all options open. There is nothing that says that after you have stored spent fuel for 30 years in a dry cask you can't then take it out and reprocess it later if technology develops that is, in fact, more promising than the traditional technologies. I should say that all of the numbers we used with respect to the cost of reprocessing are drawn from official French and British studies.

Mr. HOBSON. Yes.

Mr. BUNN. They are the French and British numbers.

Mr. HOBSON. Well, I like your final conclusions that you came to on the processing. When you talked about—I will just finish with this. When you talked about drying up, you mean on the reprocessing side of it? Because the Germans, as I understand it, are buying energy, as we speak, from——

Mr. BUNN. Yes, I mean, I——

Mr. HOBSON.—the French——

Mr. BUNN. No, I mean the customers for the reprocessing plants.

Mr. HOBSON.—facilities. Okay.

Mr. BUNN. I mean the customers are——

Mr. HOBSON. Okay. I am sorry.

Mr. BUNN.—from the reprocessing plants.

Mr. HOBSON. Well, again, thank you all for—and I want to thank the Chairwoman for this dialogue, because we weren't having this dialogue. And what we need to do is continue having this dialogue, in my opinion, so that we do move forward and not just be in a stagnant situation, because every year that—and I want to say in this forum before I leave, I am a big proponent of Yucca Mountain. I will have a huge fight with the Senate over that in getting it done. But I also understand that there are some things we have got to do along the way. And what we are both trying to do here is to create a dialogue that we move forward, and if we don't put some things into legislation and if we don't move and talk about this, we continue to be in a stagnant position, and we will continue our reliance upon fossil fuel, which I firmly believe we can not do. I don't think environmentally it is appropriate, and we just physically can't afford it in the future to continue in this way.

So I want to thank you again. I am going to have to leave, and I want to thank the indulgence of the Committee for allowing me to intrude to show support and to listen to all of your testimony.

Mr. BUNN. Thank you.

Chairwoman BIGGERT. And thank you, Chairman Hobson, for all of the work that you are doing on this. And thank you for coming today.

And with that, I would recognize Ranking Member, Mr. Honda, for five minutes.

Mr. HONDA. Thank you very much.

I am going to set aside my written questions. I am going to submit them, if you don't mind, Madame Chair, to the witnesses and expect a written response from them.

What I heard this morning is a range of opinions, but what I think I heard was that there is agreement that we need to continue on R&D. And I am judging by the nod of the heads that it sounds like that is correct.

Then the question is really is the process or the steps that we need to take in order to get to a point where we think that the disposition of spent fuel is the most appropriate and the most safe way without rushing into a solution because of political timelines and things like that? So I was just wondering from each witness what their response is to each other's comments and why they feel the way they do. I am not trying to pit one against the other, but we have witnesses here who have a lot of——

Mr. JOHNSON. A broad range of views.

Mr. HONDA.—knowledge and experience, and I would sort of like to listen to that before I ask any more questions. And we could start with Mr. Johnson.

Mr. JOHNSON. Thank you, sir.

I guess I would like to begin my answer by agreeing with your observation. I believe that what you heard this morning is there is more agreement among us than, possibly, disagreement with respect to the need of moving forward with a robust research and development program on the issue of spent nuclear fuel, recycle technologies, safeguard technologies. And the Department very much is supportive of that, and as you have seen in our budget request for the last couple of years, we are continuing to move forward in trying to walk through in a step-wise, reasonable fashion the development of the technologies needed to address the issues associated with spent nuclear fuel.

I believe I will leave my comments at that. Thank you.

Mr. HONDA. Oh, okay.

Mr. BUNN. I am a supporter of continued research and development, but I think even with respect to research and development, we need to be very careful with respect to the proliferation implications. For example, I am somewhat concerned over pursuing research and development on reprocessing technologies with South Korea, which is a country that has a formal agreement not to have either enrichment or reprocessing on its soil. It is a country that had a secret nuclear weapons program that was stopped under U.S. pressure that was based on plutonium reprocessing. And some of these technologies, while they may reduce some of the hazards of PUREX, are not as proliferation-resistant if you look at the contribution they could make to the acquisition of the needed expertise and facilities if they were broadly deployed in the developing world—the contribution to a proliferating state's nuclear weapons program.

Moreover, some of the technologies, the amount of other things that are being separated and cycled with the plutonium is pretty minor. In the case of UREX+, essentially, as I understand it, what you are—what is separated with the plutonium is the neptunium. Neptunium-237 is also a potentially attractive nuclear weapons material. So one has to worry about the possibility of theft of materials containing plutonium and neptunium-237 perhaps somewhat less than one would about theft of pure plutonium. But that is the kind of thing that requires the fact-finding examination that Dr. Hagengruber was talking about.

I should mention, since I have been questioned on the subject of our economic assumptions and so on, that I did bring a number of copies of the full study, which has the complete references and so on. It is available on-line at a link that is included in my testimony, and I would like to submit, for the record, the article-length version of which is in the current issue of Nuclear Technology.

[The information follows:]

THE ECONOMICS OF REPROCESSING VERSUS DIRECT DISPOSAL OF SPENT NUCLEAR FUEL

FUEL CYCLE AND MANAGEMENT

KEYWORDS: *reprocessing, economics, fuel cycles*

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We assess the economics of reprocessing versus direct disposal of spent fuel. The uranium price at which reprocessing spent fuel from light water reactors (LWRs) and recycling the resulting plutonium and uranium in LWRs would become economic is estimated for a range of reprocessing prices and other fuel cycle costs. The contribution of both fuel cycle options to the cost of electricity is also estimated. A similar analysis is performed to compare fast neutron reactors (FRs) with LWRs. We review available information about various fuel cycle costs, as well as the quantities of uranium likely to be recoverable at a range of future prices. We conclude that the once-through LWR fuel cycle is likely to remain significantly cheaper than recycling in either LWRs or FRs for at least the next 50 yr, even with substantial growth in nuclear power.

I. INTRODUCTION

The best approach to managing spent fuel from nuclear power reactors has been debated for decades—whether it is better to dispose of it directly in geologic repositories or reprocess it to recover and recycle the plutonium and uranium. These debates have become more salient as increasing accumulations of both spent nuclear fuel and separated plutonium from reprocessing generate concern worldwide. Countries that have chosen to reprocess are facing high costs and political controversies, while many that have chosen not to reprocess are facing obstacles to providing adequate spent-fuel storage. No country has yet opened a geologic repository for either spent nuclear fuel or high-level waste (HLW) from reprocessing. Proposals to separate and transmute not only plutonium and uranium, but other long-lived radioactive materials as well, have gained increasing attention.

Cost is an important element in this debate. Economics is not the only factor affecting decisions concerning reprocessing today—the inertia of fuel cycle plans and contracts initiated long ago, hopes that plutonium recycling will contribute to energy security, lack of adequate spent-fuel storage, environmental and proliferation concerns, and other factors also play critical roles. But economics is not unimportant, particularly in a nuclear industry facing an increasingly competitive environment and where fuel cycle costs are among the few that reactor operators can control.

There is general agreement that at today's low uranium and enrichment prices, reprocessing and recycling is more expensive than direct disposal of spent fuel.[1–3] The debate is over the magnitude of the difference and how long it is likely to persist. Advocates of reprocessing argue that the premium is small today and will soon disappear as uranium becomes scarce and increases in price.[4] Here, we argue that the margin is wide and likely to persist for many decades to come.

These issues are increasingly important as a number of countries face major decisions about future management of their spent fuel. In the United States in particular,

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16the U.S. Department of Energy (DOE) plans to spend several hundred million dollars over the next several years on research and development related to reprocessing in the Advanced Fuel Cycle Initiative.[5]

We proceed as follows. First, we compare the costs of direct disposal versus reprocessing and recycling in light water reactors (LWRs) by calculating the "breakeven" uranium price—the price of uranium at which the cost of electricity would be the same for both options—for various reprocessing prices and other fuel cycle prices and parameters. We focus on the breakeven uranium price because the prospect that rising uranium prices would make reprocessing economic has been a prominent feature of arguments made by advocates of reprocessing. We also perform a sensitivity analysis and calculate the contribution of these fuel cycle options to the cost of electricity. Second, we repeat this analysis to compare the costs of direct disposal with LWRs to reprocessing and recycling in fast neutron reactors (FRs). Third, we review the history of uranium prices, estimates of uranium resources recoverable at a given price, and scenarios of uranium consumption under the direct disposal option to assess when reprocessing and recycling in LWRs or FRs might become economically attractive. Finally, we discuss the impact of fuel cycle choices on repository requirements.

Where possible, we base our estimates on historical market prices for fuel cycle services. Where markets are not well developed, as is the case for reprocessing and mixed-oxide (MOX) fuel fabrication, our estimates are based on the best available information on facility construction and operation costs. Unless otherwise noted, prices and costs have been converted to 2003 U.S. dollars using market exchange rates and U.S. gross domestic product deflators.

II. DIRECT DISPOSAL VERSUS REPROCESSING IN LWRs

We adopt the viewpoint of an LWR operator that has discharged spent fuel and is deciding which option is less expensive: direct disposal or reprocessing. With direct disposal, the reactor operator would have to pay the costs of (a) interim storage of the spent fuel and (b) transport to a repository site and disposal of the spent fuel (possibly including conditioning prior to disposal). With the reprocessing option, the reactor operator would have to pay the costs of (a) transport to the reprocessing plant and reprocessing of the spent fuel and (b) disposal of reprocessing wastes.[a] The plutonium and uranium recovered during reprocessing can be used to fabricate MOX fuel, reducing requirements for fresh low-enriched uranium (LEU) fuel.

The value of the recovered plutonium and uranium is the value of the fuels that can be made from these materials minus the costs of fuel fabrication. Because fuels made with recovered plutonium and uranium would substitute for LEU fuels, their value is determined by the price of LEU fuel with the same design burnup, which in turn depends on the price of uranium. The uranium price at which the net present cost of the two fuel cycles is equal is the breakeven price, given notionally by

$$\begin{aligned}&\begin{bmatrix}\text{cost of interim storage }+\\ \text{disposal of spent fuel}\end{bmatrix}\\ &\quad=\begin{bmatrix}\text{cost of reprocessing }+\\ \text{disposal of wastes}\end{bmatrix}\\ &\qquad+\begin{bmatrix}\text{cost of producing LWR fuel}\\ \text{using recovered Pu, U}\end{bmatrix}\\ &\qquad-\begin{bmatrix}\text{cost of equivalent}\\ \text{LEU fuel}\end{bmatrix}\ . \qquad (1)\end{aligned}$$

Of course, many factors enter into a complete calculation—carrying charges on the cost of the material during its processing and use, fuel burnup, the isotopic composition of the recovered uranium and plutonium and the resulting plutonium concentrations or uranium enrichment levels required to achieve a given design burnup, the amount of uranium and enrichment work used to produce a kilogram of LEU at a given uranium price, and so on. The equations we have used to calculate the breakeven uranium price and the cost of electricity, which take these and other factors into account, are fully documented in Ref. 6 and have been implemented in spreadsheets that we have made publicly available.[7]

II.A. Breakeven Prices and Difference in Cost of Electricity

Figure 1 shows the breakeven uranium price as a function of the price of reprocessing [including transportation of fuel to the reprocessing plant, short-term storage of spent fuel and plutonium, treatment and disposal of low-level waste (LLW) and intermediate-level waste (ILW), and interim storage of HLW]. Table I gives central estimates of various parameters in this calculation as well as estimates that reflect best and worst cases for reprocessing. These estimates are discussed in more detail below.

The solid central line in Fig. 1 shows the breakeven uranium price using the central estimates given in Table I for other fuel cycle prices and parameters. The dotted lines labeled "Monte Carlo" show the result of a calculation in which the values of other parameters are selected randomly from independent normal distributions with 5th and 95th percentiles defined by the low and

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[a] There may be additional costs associated with storing, safeguarding, and transporting plutonium and MOX fuel, licensing MOX use in reactors, and changes in fuel management. We ignore these additional costs, an assumption favorable to the recycle approach.

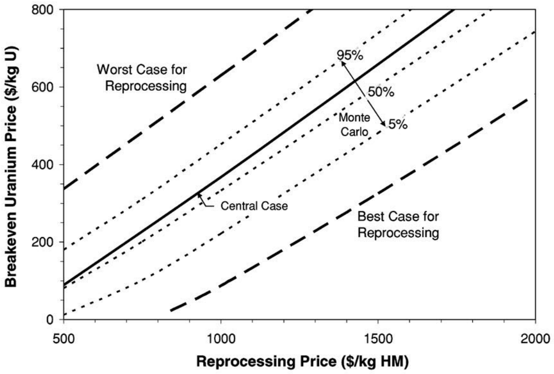

Fig. 1. Breakeven uranium price as a function of reprocessing price, for various sets of assumptions about other fuel cycle prices and parameters (see Table I).

TABLE I

Estimates of Fuel Cycle Costs and Other Parameters and Sensitivity Analysis for the Breakeven Uranium Price for Direct Disposal Versus Reprocessing and Recycling in LWRs, for a Reprocessing Price of $1000/kg HM

	Parameter Value[a]			Breakeven Uranium Price (Central = $368/kg U)		Change Compared to Central
Parameter	Low	Central	High	Low	High	
Disposal cost difference ($/kg HM)	300	200	100	298	438	±70
MOX fuel fabrication ($/kg HM)	700	1500	2300	302	434	±66
Interim fuel storage ($/kg HM)	300	200	100	310	425	±57
Enrichment ($/SWU)	150	100	50	338	404	−29 +36
Spent-fuel burnup (MWd/kg HM)	33	43	43	313	368	−54
Fresh-fuel burnup (MWd/kg HM)	53	43	43	350	368	−18
Laser enrichment	Yes	No	No	329	368	−39
Discount rate (% yr, real)	8	5	2	353	380	−15 +13
LEU fuel fabrication ($/kg HM)	350	250	150	359	376	±8
Premium for recovered uranium						
Conversion ($/kg U)	5	15	25	362	373	±5
Enrichment ($/SWU)	0	5	10	364	371	±3
Fuel fabrication ($/kg HM)	0	10	20	367	369	±1
Conversion ($/kg U)	8	6	4	367	369	±1

[a] Low = best case for reprocessing; high = worst case for reprocessing.

high values given in Table I. The outer dashed lines represent the result of setting *all* the parameters equal to those we selected as either the best or the worst case for reprocessing.

For a reprocessing price of \$1000/kg heavy metal (HM), the breakeven uranium price is about \$370/kg U for central estimates of the other parameters. This is roughly eight times the current uranium price and a level at which the available uranium resources would likely be sufficient to sustain a once-through fuel cycle for 100 yr or more, even with substantial growth (see below). Even the lower boundary of the Monte Carlo calculation represents a breakeven uranium price of about \$220/kg U for a \$1000/kg HM reprocessing price. The reason that uranium prices must increase so much to reach breakeven is that the cost of purchasing uranium is a small fraction of the overall fuel cost in the once-through fuel cycle.

Table II shows the results of breakeven calculations for selected cost parameters, holding the uranium price at \$50/kg U and setting other costs equal to the central values listed in Table I. If the uranium price is \$50/kg U, the reprocessing price would have to be reduced to below \$420/kg HM in order for reprocessing to be cost-effective. Achieving such a low reprocessing price would be an extraordinary challenge, particularly for privately owned facilities, which must pay both taxes and higher costs of money on invested capital.

Table I also gives the change in the breakeven uranium price when each of the parameters is varied from our central estimate to the worst- and best-case estimates. The parameters that have the largest impact on the breakeven uranium price are reprocessing price, difference between the disposal costs for spent fuel and HLW, MOX fuel fabrication price, and the cost of interim storage of spent fuel.

TABLE II

Breakeven Prices of Selected Parameters for Direct Disposal Versus Reprocessing and Recycling in LWRs, Assuming a Uranium Price of \$50/kg U and Central Values for Other Parameters

Parameter	Central Estimate	Breakeven Value	Breakeven: Central
Disposal cost difference (\$/kg HM)	200	630	3.2
Interim spent-fuel storage (\$/kg HM)	200	780	3.9
Enrichment (\$/SWU)	100	1200	12
Reprocessing (\$/kg HM)	1000	420	0.42
Uranium (\$/kg U)	50	370	7.4

Figure 2 shows the additional electricity cost associated with reprocessing and recycling, compared to direct disposal of spent fuel, as a function of uranium price, for several reprocessing prices, with other fuel cycle cost parameters set at their central estimates. At a

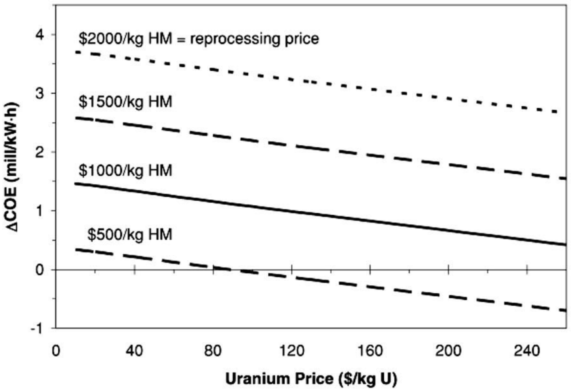

Fig. 2. The additional cost of electricity (ΔCOE, mill/kW·h) for the reprocessing-recycle option, for reprocessing prices of \$500, \$1000, \$1500, and \$2000/kg HM, compared to the cost of electricity for the direct disposal option, as a function of the price of uranium (\$/kg U).

reprocessing price of \$1000/kg HM and a uranium price of \$50/kg U, reprocessing increases the cost of electricity by 1.3 mill/kW·h, or about \$10 million/yr for a typical 1-GW(electric) LWR. If the reprocessing price is \$1500/kg HM, the cost penalty would rise to ~2.4 mill/kW·h.

II.B. Reprocessing Price

Unlike markets for uranium and enrichment services, for which published prices are widely available, virtually all aspects of the economics of reprocessing are considered proprietary information. Our estimates are therefore based on the limited information that is available from the reprocessors, other studies, and press reports. Only two companies outside the former Soviet Union operate large commercial reprocessing plants today: COGEMA, now part of the Areva group, which operates the UP2 and UP3 plants in France; and British Nuclear Fuels Limited (BNFL), which operates the Thermal Oxide Reprocessing Plant (THORP) in the United Kingdom. More is known about the costs at THORP because of the extended debates that have surrounded that facility.

THORP cost some \$5.9 billion to build.[8] While there has been considerable controversy over its reprocessing capacity (arising from its frequent failure to meet targets), we will assume 800 tonnes HM/yr. BNFL has not disclosed THORP's operating costs but stated that a similar plant would cost some \$560 million/yr to operate.[2] BNFL subsequently asked for additional payments from customers to cover higher-than-expected capital and operating costs.[9] Nevertheless, to be conservative, we will rely on this early BNFL estimate.

Both THORP and the UP3 plant were built with very favorable financing arrangements—pay-ahead contracts from utility customers paid essentially the entire capital cost over a 10-yr "base-load" period. Recovering a capital cost of \$5.9 billion over 10 yr (without interest) would contribute \$740/kg HM to the reprocessing cost. Including operational costs of \$700/kg HM, start-up costs equal to 1 yr of operational costs, and refurbishment and decommissioning costs of \$100/kg HM, the total reprocessing cost is about \$1800/kg HM. Indeed, BNFL figures (adjusted for inflation) indicate that base-load contracts amounted to about \$2300/kg HM (Ref. 8), which is consistent with expected costs plus a fee of ~25%.

The cost of reprocessing at new facilities with capital and operating costs comparable to THORP would depend crucially on how they were financed. Using the financing assumptions given in Ref. 10, a government-owned facility would have a total reprocessing cost of about \$1350/kg HM; a private facility with a guaranteed rate of return like that which pertains to regulated utilities would have a cost of roughly \$2000/kg HM; and a private facility with no guaranteed rate of return would have a cost of more than \$3100/kg HM—all for the same capital and operating costs estimated for THORP.

Costs and base-load contract prices for the UP3 plant, built at roughly the same time to meet essentially the same market, have been reported to be generally similar to those for THORP, though much less detail is available. Costs for the most recent large reprocessing plant, the Rokkasho-Mura plant nearing completion in Japan, have been much higher. The capital cost of the Rokkasho-Mura plant is now expected to be roughly \$18 billion, and the operations cost is expected to be more than \$1.4 billion/yr (Ref. 11)—both about three times the THORP costs.

Post-base-load contracts for THORP and UP3 were reportedly concluded in 1989 to 1990 at prices in the range of \$1000 to \$1500/kg HM (Refs. 2, 3, 8, 12, and 13). More recently, prices offered for new reprocessing contracts have reportedly fallen to \$600 to \$900/kg HM (Ref. 13), representing the operational cost plus a small profit. These low prices are only possible because recovery of capital is no longer included and therefore do not represent sustainable prices for reprocessing services.

In short, the \$1000/kg HM reprocessing price we have used as our central estimate is quite conservative. For facilities with capital and operating costs comparable to THORP, costs in this range could only be achieved for facilities whose capital cost has already been paid off or that are government financed. If, as seems likely, financing for future plants would have to be raised on private capital markets, a price of \$1000/kg HM would require more than a 50% reduction in the capital and operating costs even for entities with a guaranteed government-regulated rate of return.

Can the cost of reprocessing be reduced substantially? The Plutonium Redox Extraction (PUREX) process used in existing facilities has been perfected over more than five decades. While refinements are possible (and ongoing), it seems unlikely that dramatic cost reductions could be achieved using this or similar technologies. Although some argue that costs could be reduced using the experience gained from existing plants, very substantial reductions would be needed just to get to our assumed \$1000/kg HM cost, even for government-financed facilities and especially for the more likely future case of privately financed facilities. Moreover, increasingly stringent environmental and safety regulations will put countervailing pressures on costs. According to a recent report to the French government, building a new plant similar to UP3 would cost \$6 billion—the same as the original plant.[14]

A wide range of alternative chemical separations processes have been proposed over the years. Recently, attention has focused on electrometallurgical processing or "pyroprocessing." A 1996 review by a committee of the National Academy of Sciences, however, concluded that the cost estimates provided in studies of the processes in the mid-1990s were "inexplicably low," that "it is by no means certain that pyroprocessing will prove more economical than aqueous processing," and that the costs of current plants such as THORP and UP3 "provide the most reliable basis for estimating the costs of future plants."[10] More recently, official reviews have concluded that such techniques are likely to be substantially more expensive than traditional aqueous reprocessing, with a nominal estimate of \$2000/kg HM (2.5 times higher than their nominal estimate of \$800/kg HM for traditional reprocessing) in two of the most recent analyses.[15,16]

In short, while future technological developments hold some promise, it does not appear likely that within the next few decades the cost of reprocessing, including payback of capital costs of facilities (likely at commercial costs of money), will be reduced to prices that would allow reprocessing to compete economically with uranium at prices likely to pertain for most of this century. Indeed, it is possible that costs could increase—as suggested by the remarkable increase in cost of Rokkasho-Mura compared to THORP and UP3—driven by the costs of meeting more stringent environmental and safety requirements.

II.C. Waste Disposal Cost Difference

The next most important parameter is the savings resulting from treatment and disposal of reprocessing wastes as compared with direct disposal of spent fuel. Permanent geologic disposal of spent fuel and HLW has not been demonstrated, and approaches to waste disposal vary considerably from country to country, making cost estimates highly uncertain.[17]

The U.S. geologic disposal program has prepared the most detailed public analyses of any program in the world. The most recent cost estimate for the U.S. repository program is \$57.5 billion (in 2000 dollars), of which \$41.8 billion is for the disposal of 83 800 tonnes HM of civilian spent fuel.[18] This is financed by charging utilities a fee of 1 mill/kW·h, which is equivalent to about \$370/kg HM at the time of discharge.[b] With interest, this fee is expected to be sufficient to fund the full costs of transport to the repository, encapsulation, and disposal of the spent fuel, including all future repository construction and operations costs.[19]

Cost estimates produced by other countries for the disposal of spent fuel are roughly comparable. Sweden, for example, released a cost estimate in 1998 of \$300 to \$350/kg HM (Ref. 20). While it remains possible that these total cost estimates will continue to grow in the future, \$400/kg HM at time of discharge is a reasonable benchmark for total disposal cost of spent fuel. Thus, our central estimate of \$200/kg HM for the cost difference implies that reprocessing would reduce waste disposal costs by 50%.

Spent fuel and HLW differ in a number of ways that could affect disposal costs. The most important characteristics are the heat, volume, and mass of the waste and the number of waste packages to be handled.

The heat output from waste packages determines how close to each other they can be placed while remaining within the repository's design temperature constraints. Thirty yr after discharge, the heat output from the vitrified HLW is ~70% of the heat output of the original spent fuel—and the heat output of the HLW declines more rapidly than that of the spent fuel thereafter.[10,17] This reduction in heat output at 30 yr may offer even greater packing efficiencies, as the spaces between HLW packages could be left empty at first, while additional canisters were emplaced for the next 60 yr, during which time another fourfold reduction in heat output would take place. New waste packages could then be put between the first canisters emplaced, while remaining within the original heat limits. Although a similar strategy could be pursued with spent fuel, it does not offer as dramatic a benefit because spent fuel cools more slowly than HLW.

Waste volume and mass affects waste package and transportation costs. The volume of vitrified HLW waste is roughly one-quarter the volume of the original spent fuel; including packaging for geologic disposal, the total volume per kilogram of original HM ranges from roughly equal to half as large for the HLW. Hence, reprocessing might reduce volume-related costs by as much as 50%.

Some costs increase with the number of items handled—fuel assemblies or HLW canisters to be loaded into waste packages, waste packages to be emplaced, and the like. A NIREX study estimated that each HLW waste package would hold two canisters of HLW, each containing HLW from the reprocessing of 1.2 tonnes HM of spent fuel.[21] Thus, there would be 0.8 HLW canisters and 0.4 waste packages/tonne HM for the reprocessing option, compared to 2.2 fuel assemblies and 0.54 waste packages/tonne HM for direct disposal, for an overall reduction in item-related costs of ~30% (Ref. 22).

We can get a rough idea for how much reprocessing might reduce waste disposal cost by dividing costs into components that are affected by various waste disposal characteristics and assigning notional reduction factors for the disposal of HLW rather than spent fuel. In the case of the U.S. Yucca Mountain repository, heat-related costs (repository construction and drip shield) amount to 19% of total program costs; those related to volume, mass, or number of items (repository emplacement operations and monitoring, waste package fabrication, and transportation) are 53%; and other costs (siting, licensing, design, and engineering) contribute 28% (Ref. 18). We assign a fourfold reduction factor for heat-related costs and costs not related to waste form (corresponding to a potential fourfold increase in the amount of fuel that could be emplaced in the repository) and a twofold reduction factor for costs related to volume, mass, or number of items.

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[b] In 2003 dollars, assuming a burnup of 43 000 MWd/tonne HM, a net efficiency of 33%, a core residence time of 4 yr, and discounting at a real rate of 0.05/yr.

The previous discussion does not include the management and disposal of ILW and LLW from reprocessing. BNFL has permission from the British government to address the cost of LLW disposal through "substitution"—adding a small amount of HLW to the amounts sent back to customers instead of returning the LLW. BNFL hopes to get similar permission for ILW, and if this were granted, the total amount of HLW returned to each customer would be ~20% higher than the amount generated by reprocessing of that customer's spent fuel.[6] If the reprocessors are required to return all ILW and LLW, costs of management of these wastes would be higher. We therefore assume that total disposal costs are 20% greater than the cost of HLW disposal alone. Applying this and the factors listed above results in an overall cost reduction of 55% due to disposal of reprocessing wastes rather than spent fuel, which corresponds well with our central estimate of $200/kg HM for the cost savings due to reprocessing. Given the large uncertainties in such estimates, we have used a range from a difference of $100 to $300/kg HM.

A 1993 Organization for Economic Cooperation and Development–Nuclear Energy Agency (NEA) study[17] compared the estimated repository costs for many countries (considering only encapsulation and disposal costs) and found that the weighted average cost was 57% less for disposal of HLW compared to spent fuel. A recent French study offers substantially lower figures for disposal costs ($80/kg HM for HLW and $130/kg HM for spent LEU fuel),[1] but the percentage reduction for reprocessing (40%) is roughly in line with our central estimate (50%). A recent review of future fuel cycle options by a group advising the DOE estimated a cost of $200/kg HM for disposal of HLW compared with $300/kg HM for spent fuel,[16] consistent with the low end of our range for the cost difference. An NEA review of transmutation technologies also provided estimates that are consistent with the low end of our range.[c]

We have assumed that spent MOX fuel is not reprocessed and that the disposal costs are equal for spent MOX and LEU fuels of equal burnup. Most countries that now recycle plutonium do so only once because of the buildup of undesirable isotopes in spent MOX fuel. The heat output of spent MOX fuel is much higher than that of spent LEU fuel—2.2 versus 0.7 W/kg HM 50 yr after discharge, for a burnup of 43 MWd/kg HM (Ref. 23). The greater heat output of spent MOX fuel should result in substantially higher disposal costs. If, for example, disposal of spent MOX fuel costs $400/kg HM more than spent LEU (twice the central value of $400/kg HM for LEU), the breakeven uranium price would increase by $26/kg U. If, on the other hand, spent MOX fuel is reprocessed and the recovered plutonium is used in a "self-generated recycle" mode, the total heat output from the HLW from that fuel cycle is higher, per unit of electricity generated, than that of the once-through cycle for the first 50 yr after discharge from the reactor,[24] negating much of the cost advantage for disposal of HLW compared to spent fuel.

II.D. MOX Fuel Fabrication Price

The principal cost in using recovered plutonium is the price of fuel fabrication. Like reprocessing, fabricating MOX fuel is expensive because it requires large, capital-intensive facilities and highly trained personnel. It is substantially more expensive than fabricating LEU fuel primarily because of the safety requirements resulting from the much higher radiotoxicity of plutonium and also because of the greater safeguards and security requirements when handling weapons-usable material. As with reprocessing, the industry is dominated by a small number of firms (COGEMA, BNFL, and Belgonucléaire), and virtually no official information on costs and prices is publicly available.

Again, because of the public controversies surrounding it, most is known about BNFL's Sellafield MOX Plant (SMP), designed for a capacity of 120 tonnes HM/yr. SMP is officially estimated to have cost $540 million[25]; when the cost of financing over the prolonged construction period and the subsequent delays in gaining approval are included, the cost increases to about $750 million.[8] Similarly, Siemens' 120 tonnes HM/yr plant at Hanau, Germany, which was built but never operated, reportedly cost roughly $750 million.[26] In 1993, the DOE estimated that the overnight cost of building a facility with a capacity of 100 tonnes HM/yr in the United States would be $440 million, or about $550 million in 2003 dollars.[27]

Current estimates for new plants in Japan and the United States are substantially higher. The overnight cost of building a MOX plant in the United States for disposition of excess weapons plutonium is currently estimated at more than $1 billion (not counting more than $300 million in research and development and precapital expenses and another $500 million for contingencies).[28] A portion of the cost of this facility will go to removing gallium and other impurities from weapons plutonium before it is fabricated into MOX fuel, but even if this represented 30% of the total, the remaining overnight cost would be $700 million. Similarly, the Rokkasho MOX Plant in Japan, with a planned capacity of 130 tonnes HM/yr, is expected to cost roughly $1 billion.

Operating costs at existing MOX plants have not been published. One group has estimated the operating costs of SMP at roughly $50 million/yr (Ref. 29). This is

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[c] The central estimates in Ref. 15 were $400 000/$m^3$ for HLW conditioning and disposal and $210 000/$m^3$ for spent fuel. Converting these to tons of original spent fuel using a relatively low estimate of 0.8 m^3/tonne HM for HLW and a relatively high estimate of 2 m^3/tonne HM for spent fuel, we have $320/kg HM for HLW and $420/kg HM, or a disposal cost difference of $100/kg HM.

consistent with an analysis that concluded that operations costs in a facility of this kind would amount to \$560/kg HM (Ref. 30); with the low end of an NEA estimate that the operating costs of such facilities are in the range of 10 to 25% of their capital costs[15]; and with annual operating costs (including an annuity for decommissioning) of \$76 million/yr estimated in the 1993 DOE study.[27] The operating costs for the planned U.S. MOX plant are expected to be in the range of \$100 million/yr (Ref. 28), which would be consistent with the earlier DOE estimate if 30% of the operating cost goes to purification of weapons plutonium.

If a plant with the reported capital cost of SMP and a \$560/kg HM operating cost succeeded in producing 100 tonnes HM/yr throughout a 30-yr life, the fabrication cost (with assumptions similar to those above for reprocessing plants) for a government-financed facility would be about \$1000/kg HM; for a regulated private facility with a guaranteed rate of return, \$1500/kg HM; and for a private facility with no guaranteed rate of return, \$2100/kg HM. Transport of MOX fuel is a significant extra cost that must be added to these figures.[30]

These costs apply for large fabrication campaigns of fuel of the same design. When a customer needs only a modest amount of MOX fuel, using different design parameters from those used by other customers, throughput suffers and per-kilogram costs increase substantially. Per-kilogram costs also increase if demand is not sufficient to keep the plant fully booked.

MOX fabrication prices, like costs, are not publicly divulged. For essentially all of the 1980s and 1990s, demand was higher than supply and prices were higher than one would expect based on the costs given above. One review indicates that in the 1980s prices were \$1900 to \$2400/kg HM, while in the 1990s they were \$2100 to \$2700/kg HM (Ref. 13). A DOE survey of fabricators in 1993 reported a range of offers centering on \$1850/kg HM (Ref. 27). Eléctricité de France enjoys lower prices of about \$1200/kg HM, as it buys very large quantities of a standard product and has a special relationship with COGEMA and its MELOX plant.[1,31] German and Swiss utilities, on the other hand, report much higher prices, in the range of \$3000 to \$4000/kg HM, which reflect their smaller purchases and the fact that much of their fuel has been fabricated in smaller, less automated plants.[3,32] With SMP now open and the supply of MOX fabrication services likely outstripping demand, prices may fall significantly—although MOX fabrication firms will still have substantial leverage to demand high prices because the only alternative for utilities with separated plutonium is to pay for plutonium storage at rates determined by the same firms.

MOX fuel fabrication is less mature than PUREX reprocessing, leaving more room for further technical improvement and cost reduction in the future. As one recent review put it, "new plants would benefit greatly from the extensive experience gained during the last decades, thereby allowing them to simplify the plants, decrease their size, and reduce maintenance requirements."[15] If, however, the focus remains on pellet-based fuels, manufacturing each pellet to stringent standards will continue to be an expensive process, and there may be limits to the scope for cost reductions. Modern MOX fabrication facilities are already highly automated and designed to minimize maintenance. Moreover, as with reprocessing, there may be trends that would increase per-kilogram costs over time—including not only increasing demands for more stringent safety and security precautions (a substantial factor driving the cost of the planned U.S. MOX plant), but also customer demands to fabricate fuels with higher design burnup, using plutonium recovered from higher-burnup spent fuel or plutonium that has been stored for long periods and therefore has higher americium content.

There may also be opportunities for new technologies that could simplify plutonium fuel fabrication and reduce cost, such as "vibropak" fuels, in which the plutonium and uranium powders are packed into the fuel pins by vibration, with no pellet manufacturing required. Further development is required to determine whether such approaches can offer substantial MOX fuel cost reductions and whether they can be used in existing LWRs or only in reactors designed for their use.

Overall, our central estimate of \$1500/kg HM is low with respect to recent prices but reasonable for a future world in which supply and demand is balanced and prices more closely reflect production costs. Our \$700/kg HM lower bound would require either very substantial technological innovation or sales from facilities whose capital costs are already amortized and which therefore do not reflect a long-run sustainable cost for providing the service. The \$2300/kg HM upper bound is in the range of prices already charged at existing facilities and could reflect future prices if societal and customer demands drive costs higher in the future.

In many cases, there are additional costs to a reactor operator associated with using MOX rather than LEU fuel, which, to be conservative, we have not included in this analysis. First, MOX fuel is often licensed to lower burnups than LEU fuel, which would require reactor operators to shut down for refueling more often. Second, because fresh MOX fuel contains weapons-usable plutonium, it requires more security than would fresh LEU fuel, often imposing additional costs. (In some cases fresh MOX fuel is simply placed with spent fuel at the reactor site, without any additional facilities or security arrangements, on the assumption that it would be difficult and dangerous for attackers to remove it from the pool.) Third, in a number of countries there are substantial political concerns over the use of MOX and additional licensing requirements for reactors wishing to use both MOX and LEU fuels. Hence, the value of MOX fuel (if there were an open market allowing utilities to choose their fuels) would not be equal to that of LEU fuel of equal design burnup, as is assumed here. In the case of the U.S. program for disposition of excess weapons plutonium, for example, persuading U.S. utilities to use MOX fuel required offering it at a price some 40% below the price of LEU fuel of equivalent energy value[33]—equivalent to increasing the net fabrication price for the MOX fuel by several hundred dollars per kilogram. Fourth, we have assumed a reprocessing and recycling system that is operating efficiently and in balance, so that there are no charges for storing plutonium or for removing americium. Commercial rates for these services are estimated at \$1000 to \$2000/kg·yr for storage and \$10 000 to \$28 000/kg for americium removal.[15] Including several years of plutonium storage and one round of americium removal would increase the effective cost of MOX fabrication by \$1000 to \$3000/kg HM and would increase the breakeven uranium price by \$80 to \$250/kg U.

II.E. Cost of Interim Spent-Fuel Storage

For reactor operators who choose reprocessing, interim storage of spent fuel for decades is not required. Interim storage generally is required for direct disposal, however, as repositories are not expected to be available for several decades. We have therefore included interim storage as an extra cost for the direct disposal fuel cycle, although new reactors are being built with pools able to accommodate storage of all the fuel they will generate in their lifetime, reducing or eliminating this extra storage cost. Costs of interim storage can vary significantly depending on the technology chosen, whether fuel is to be transported to a centralized site or kept at reactor sites (and, if at a reactor site, whether the reactor is operating), whether taxes or other payments must be made to local, regional, or national governments, and the like.

Dry-cask storage is a well-established technology for storing spent fuel for decades with minimal operating costs. In the United States, total up-front costs to establish a new dry storage facility at a reactor site (which are largely fixed regardless of the amount of spent fuel to be stored) are estimated at roughly \$10 million.[34,35] Costs to purchase and load the casks—including labor, consumables, and decommissioning—are estimated at \$70 to \$90/kg HM (Ref. 34). The principal operating costs are providing the security and safety monitoring needed to maintain the Nuclear Regulatory Commission license for the facility. For storage sites colocated with operating reactors, many of these costs can be charged to the reactor operation, and the net additional operating costs are estimated to be about \$800 000 yr (largely independent of the amount of spent fuel to be stored).[34] Total costs for 40 yr of dry-cask storage of 1000 tonnes HM at an operating reactor site in the United States would be in the range of \$100 to \$120/kg HM (with operational costs discounted at 3%/yr).

For storage at shutdown reactors or independent sites, the costs of maintaining the license, including security and safety personnel, must be attributed entirely to the storage facility, making its operational cost substantially higher. For shutdown reactors with all their spent fuel in dry storage, operating costs are estimated to be \$3.3 to \$4.4 million/yr (Refs. 34 and 35). Total cost for 40 yr of storage in this case would range from \$150 to \$200/kg HM. A large centralized facility could spread these operations costs over a larger amount of spent fuel, but there would be additional up-front costs for transportation to the centralized site.

Somewhat higher costs have been estimated in Japan; in a 1998 study, total discounted costs for 40 yr of storage in a 5000-tonne centralized dry-cask facility were estimated at \$280/kg HM (Ref. 36). These costs do not include benefits that may be paid to the local community to build public acceptance and gain government approval, which could in some cases be substantial.

We have chosen \$200/kg HM as our central estimate of interim-storage costs, which is comparable to the discounted cost of independent dry-cask storage in the United States at small facilities. The lower estimate of \$100/kg HM is close to the current cost of at-reactor dry-cask storage in the United States, while the upper limit of \$300/kg HM may represent the cost at independent facilities, including payments to nearby communities.

II.F. Other Fuel Cycle Prices and Parameters

Other factors—enrichment and LEU fuel fabrication prices, premiums for the use of recovered uranium, fuel burnup, and discount rate—are less important when comparing the economics of direct disposal versus reprocessing and recycling in thermal reactors.

Long-term contract prices for enrichment services fell from earlier levels of more than \$100/separative work unit (SWU) (in then-year dollars) to \$85/SWU by late 1999, only to increase back to some \$110/SWU in 2001 (Ref. 37). The gap between long-term and spot SWU prices has declined substantially; in the first half of 2004, the spot price in the United States was about \$110/SWU (Ref. 38). One projection in mid-2003 suggested that SWU prices in long-term contracts would likely remain in the range of \$105/SWU for a few years and then rise slightly toward the end of the decade.[39] Production costs of gas-centrifuge enrichment are below \$80/SWU and can be expected to decrease as the next generation of centrifuges is installed.[13] The NEA has estimated that enrichment prices in the short to medium term will be in the range of \$80 to \$120/SWU; over the longer term, the NEA reports that new facilities using advanced processes might reduce costs to \$50/SWU (Ref. 40). We have chosen a central estimate of \$100/SWU, with a high of \$150/SWU and a low of \$50/SWU, allowing a somewhat broader range of possibilities.

The NEA projects LEU fabrication prices in the short to medium term at \$200 to \$300/kg HM (Ref. 40). A previous survey by a National Academy of Sciences committee chose a central estimate of \$250/kg HM (Ref. 27). This central estimate is somewhat higher than recent prices in the U.S. market but somewhat lower than most prices in the European market.[41] We have chosen a central estimate of \$250/kg HM, with a low of \$150/kg HM and a high of \$350/kg HM, again allowing a somewhat broader range of possibilities than the NEA projections. The technology of LEU fuel fabrication is mature and the safety and health impacts modest, so it appears unlikely that this price will change substantially in the future.

Uranium recovered from reprocessing contains undesirable isotopes such as ^{232}U (whose radioactive daughter products emit penetrating gamma rays) and ^{236}U (which is a neutron absorber, increasing the enrichment required to achieve a given design burnup). Because of the higher radioactivity of recovered uranium, firms charge higher prices for its conversion, enrichment, and fabrication. If natural uranium is cheap, recovered uranium has no value at all. Indeed, most utilities have not bothered to recycle recovered uranium, and the vast majority of all the uranium recovered from the reprocessing of LWR fuel remains in storage. Market estimates of the relevant premiums are therefore somewhat uncertain.[13] We have chosen central estimates of \$15/kg U for conversion, \$5 for enrichment, and \$10 for fuel fabrication.[15] Recovered uranium would become more valuable if laser isotope enrichment is commercialized because laser enrichment would remove the undesirable isotopes.

Conversion of uranium from U_3O_8 to UF_6 for enrichment is a minor cost element. We have chosen a central estimate of \$6/kg U, with a range of \$4 to \$8/kg U. The NEA projects conversion prices in the short to medium term in the range of \$3 to \$8/kg U, nearly identical to our range.[40]

Recycle becomes less attractive economically as the burnup of the reprocessed spent fuel increases because the isotopic quality of the recovered plutonium and uranium declines.[42] On the other hand, increased design burnup of the fresh fuel makes recycle more attractive because the additional enrichment required makes LEU relatively more expensive.[27] We have taken, as our best case for reprocessing, the fabrication of MOX with a design burnup of 53 MWd/kg HM using plutonium recovered from spent fuel with a burnup of 33 MWd/kg HM. Our central and worst-case estimates have spent- and fresh-fuel burnups of 43 MWd/kg HM.

All fuel cycle services are discounted to the time of fuel discharge. We use a central value of 0.05/yr for the real discount rate, which is roughly the debt rate available to a regulated utility with a guaranteed rate of return. We adopt a range of 0.02 to 0.08/yr, which has a modest effect on our calculations. The geologic disposal cost difference is the net present value at the time of fuel discharge.

III. DIRECT DISPOSAL IN LWRs VERSUS RECYCLE IN FRs

From the dawn of the nuclear age, the nuclear industry believed that uranium was relatively scarce and that the number of reactors would grow rapidly, leading to rapidly rising uranium prices. Hence, the industry projected that there would be a rapid transition from LWRs, which rely heavily on fissioning the rare ^{235}U isotope, to FRs, which more efficiently transform ^{238}U into plutonium that is either fissioned in place or recycled via fuel reprocessing. The recycling of plutonium in LWRs was seen only as a temporary expedient until the transition to primary reliance on FRs began.

The transition to FRs has taken much longer than once expected. Uranium has turned out to be abundant and cheap, nuclear energy has grown much more slowly than expected, and FRs have been more expensive and problematic than anticipated. As a result, only Russia, India, and Japan still have near-term plans for commercializing FRs. Russia is the only country that operates a commercial-scale FR (the BN-600); construction of a slightly larger plant, the BN-800, has recently resumed after having been largely on hold since the 1980s. The United States, France, Britain, Germany, and other countries have terminated FR commercialization efforts, though in a number of countries longer-term research and development continues. More recently, as part of efforts to develop advanced systems for a possible future resurgence of nuclear energy, FRs have again received increased attention as a long-term option.[43]

III.A. Breakeven Prices and Difference in Cost of Electricity

At what uranium price would recycling in FRs become economical? To answer this question we must account not only for differences in fuel cycle costs but also for the fact that the capital costs of FRs and LWRs may be different. (We have assumed for the sake of simplicity that the nonfuel operations and maintenance costs of LWRs and FRs would be the same; this is a generous assumption, as studies have suggested that FRs would have higher nonfuel operations and maintenance costs.[44,45]) The estimated capital costs of sodium-cooled FRs have typically been up to 50% higher than those of LWRs. As with reprocessing and MOX fuel fabrication plants, we explore three different financing arrangements for this additional capital cost, appropriate for facilities owned by a government, by a regulated utility, and by an unregulated electricity producer.

Figure 3 gives the breakeven uranium price as a function of the difference in capital cost between LWRs and

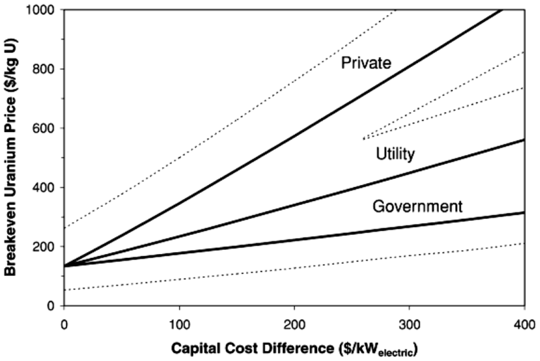

Fig. 3. Breakeven uranium price for LWR with direct disposal and FR, as a function of capital cost difference, for reactors financed by government, a regulated utility, and a private electricity producer, for central values of other parameters (see Table IV).

FRs for the three financing arrangements. The characteristics of the generic FR are given in Table III. Table IV gives our central, low, and high estimates for the various cost parameters used to produce these graphs, along with the sensitivity of the outcome to changes in each parameter. The dotted lines in Fig. 3 represent the results of a Monte Carlo calculation in which these parameters are selected randomly from independent normal distributions with the 5th and 95th percentiles defined by the low and high values given in Table IV.

TABLE III

Characteristics of the Generic FR*

Parameter	Low	Central	High
Breeding ratio	1.0	1.12	1.25
Annual blanket loading (kg HM/MW(electric)·yr)	19.0	25.5	31.9
Annual core loading (kg HM/MW(electric)·yr)		11.5	
Residence time of core elements (yr)		3.0	
Residence time of blanket elements (yr)		3.2	
Plutonium fraction in core		0.246	
Makeup fraction in blanket		0.024	
Efficiency (net MW(electric)/MW(thermal))		0.38	

*Reference 16.

We have chosen the reactor owned by a regulated utility with a guaranteed rate of return as the reference case for the sensitivity analysis in Table IV. This may be a generous assumption given the global trend toward increased reliance on privatized power plants operating in competitive electricity markets. While there remain some major countries where power plants are built and operated by a government-owned monopoly, this is not likely to be the case in most countries that will have to consider the choice between once-through LWRs and FRs with recycling.

As shown in Fig. 3 and Table IV for the case of a utility-owned reactor, if the capital cost of FRs is $200/kW(electric) greater than that of LWRs and other parameters are held at their central values, FRs with recycling would not be economic unless the price of uranium rose to more than $340/kg U—similar to our central estimate of the breakeven price for recycle in LWRs. Differences in capital cost between FRs and LWRs are less important for government-owned facilities and more important for a private venture; for a capital cost difference of $200/kW(electric), the breakeven uranium price ranges from $220/kg U for the former to $570/kg U for the latter. Even if the capital cost of FRs is equal to that of LWRs (in which case the type of financing is irrelevant to the comparison), the breakeven uranium price under the same assumptions is $130/kg U—a price that is unlikely to be seen for decades.

One assumption we have made in these calculations should be noted. Because there are currently hundreds of

TABLE IV

Estimates of Fuel Cycle Costs and Other Parameters and Sensitivity Analysis for the Breakeven Uranium Price for Direct Disposal in LWRs Versus Reprocessing and Recycling in FRs, for Reactors Owned by a Regulated Utility

Parameter	Parameter Value			Breakeven Uranium Price (Central = $340/kg U)		Change Compared to Central
	Low	Central	High	Low	High	
Capital cost difference [$/kW(electric)]	0	200	400	134	560	−205 +221
Reactor owner	Government	Utility	Private	222	574	−118 +234
Reprocessing cost ($/kg HM)	500	1000	2000	255	516	−85 +176
Enrichment ($/SWU)	150	100	50	282	415	−58 +75
FR core fabrication ($/kg HM)	700	1500	2300	286	394	±54
FR breeding ratio	1.0	1.12	1.25	294	386	±46
Geological disposal cost difference ($/kg HM)	300	200	100	322	358	±18
LEU burnup (MWd/kg HM)	43	53	53	322	340	−17
Construction time (yr)	3	6	9	326	355	±15
FR blanket fabrication ($/kg HM)	150	250	350	325	355	±15
LEU fuel fabrication ($/kg HM)	350	250	150	327	353	±13
Capacity factor (%)	90	85	80	328	353	±13
Preoperating, contingency costs (%)	5	10	15	330	350	±10
Interim spent-fuel storage ($/kg HM)	300	200	100	332	348	±8
Conversion ($/kg U)	8	6	4	338	342	±2
DU ($/kg)	6	6	Uranium price	340	341	+1

tons of separated plutonium in storage, we have assigned zero cost to the plutonium needed for the initial FR core. Past analyses have assumed that the cost of reprocessing LWR fuel to recover plutonium for the initial core would be charged to the cost of the FR, with the cost capitalized over the life of the reactor.[46,47] This assumption may be more accurate because if FRs are deployed in numbers large enough to make a substantial contribution to world electricity demand, existing stockpiles of separated plutonium will not be sufficient to start them up, and reprocessing of spent LWR fuel to provide the necessary plutonium would be needed. If the cost of reprocessing LWR fuel was $1000/kg HM and each kilogram of LWR fuel provided ~10 g of plutonium, the cost of start-up plutonium would be $100 000/kg; accounting for savings in interim spent-fuel storage and waste disposal costs ($200/kg HM each) and the value of the recovered uranium (of order $300/kg U by the time FRs might be competitive), the net cost would be on the order of $30 000/kg. In that case, the plutonium for the start-up fuel (the initial core plus one-third core for the first refueling) would add $340/kW(electric) to the cost of the FR. [Highly enriched uranium (HEU) could be used for the initial core, but the cost would be even higher.[d]] The cost of the start-up plutonium could be offset somewhat by the sale of excess plutonium generated during the operation of the reactor; this would reduce the net plutonium cost to about $200/kW(electric).[e] Thus, even if other FR capital costs are reduced to those of LWRs, the uranium breakeven price would still be at our central

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[d] The start-up core and initial reload would require 46 kg/MW(electric) of HEU with an enrichment of ~25% ^{235}U. Assuming uranium, conversion, and enrichment prices of $50/kg U, $6/kg U, and $100/SWU, respectively, the cost would be $8300/kg of HEU, equivalent to $380/kW(electric). Using the breakeven price of uranium in our reference case ($340/kg U) would increase these costs to $22 000/kg and $1000/kW(electric).

[e] With a breeding ratio of 1.25 the FR produces surplus plutonium at a rate of 0.3 kg/MW(electric)·yr; assuming a value of $30 000/kg and a discount rate of 0.05/yr over 30 yr, and taking into account the plutonium recovered from the final core, the net present value at start-up of the surplus plutonium is $130/kW(electric).

TABLE V

Breakeven Prices of Selected Parameters for Direct Disposal in LWRs Versus Reprocessing and Recycling in FRs, Assuming a Regulated Utility Owner, a Uranium Price of $50/kg U, and Central Values for Other Parameters

Parameter	Central Estimate	Breakeven Value	Breakeven: Central
Capital cost difference [$/kW(electric)]	200	−95	
Disposal cost difference ($/kg HM)	200	3400	17
Interim spent-fuel storage ($/kg HM)	200	4100	21
Enrichment ($/SWU)	100	570	5.7
Reprocessing ($/kg HM)	1000	<0	
Uranium ($/kg U)	50	340	6.8

estimate of about $340/kg U for our central values of other parameters.

Table V gives breakeven values of several other price parameters for the case of a regulated utility owner assuming a uranium price of $50/kg U and central values for other parameters. Note that reductions in the price of reprocessing alone cannot make FRs economic so long as the FRs remain $200/kW(electric) more expensive than LWRs.

Figure 4 shows the difference between the cost of electricity from FRs with recycling and LWRs operating on a once-through cycle, as a function of the price of uranium, for differences in capital cost ranging from $0 to $400/kW(electric), assuming utility-owned reactors and other parameters set at their central values. The electricity price for FRs will remain significantly higher than that for LWRs operating on a once-through cycle until the uranium price increases to at least several times its current level—a development that is not likely to occur for many decades to come.

This overall finding is broadly consistent with other recent studies. An NEA assessment found that the cost of electricity from FRs with recycle of plutonium and minor actinides would be 50% higher than from LWRs operating on a once-through cycle.[15] The Generation IV Fuel Cycle Crosscut Group examined the fuel cycle contribution to electricity costs for different types of nuclear energy mixes throughout the 21st century, during which time they projected uranium prices to increase dramatically. Despite those projected increases (and despite looking only at fuel cycle costs and therefore not including any increased capital cost of FRs), the costs for all the mixes that included FRs remained higher throughout the century than the price for electricity from once-through LWRs (Ref. 16). Similarly, a mid-1990s study by a committee of the National Academy of Sciences concluded that the electricity cost of FRs would be substantially higher than that of once-through LWRs until uranium reached a price of well over $250/kg U (in 1992 dollars),

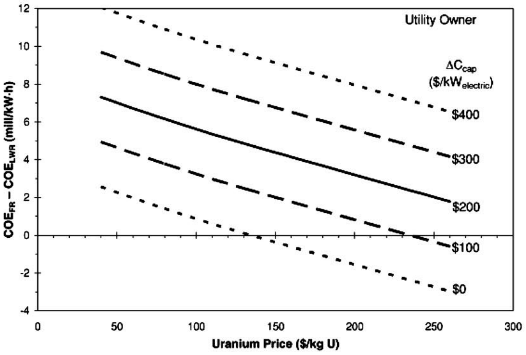

Fig. 4. The difference in the cost of electricity between an FR with recycling and an LWR with direct disposal as a function of the price of uranium, for differences in the initial capital cost of $0, $100, $200, $300, and $400/kW(electric), assuming utility ownership.

even if reprocessing costs for LWR fuel and FR fuel were at the lower bounds given here.[10]

III.B. Capital Cost Difference and Related Factors

The most sensitive parameters in this analysis are the difference in capital cost between FRs and LWRs and the financing arrangements for capital costs. We have assumed a central value of \$200/kW(electric) for the difference in capital cost, with a range of \$0 to \$400/kw(electric). This range reflects past experience and peer-reviewed estimates for the additional capital cost of FRs and the expectation that there would be further progress in bringing FR costs down.

The most recent FR designs in the United States and Western Europe were expected to be significantly more expensive than LWRs. The capital cost of the U.S. Advanced Liquid Metal Reactor (ALMR) was estimated in the mid-1990s, shortly before the program's termination, to be 20 to 30% higher than that of advanced LWRs (a difference of \$500 to \$740/kW(electric) in 2003 dollars).[27] Similarly, the European Fast Reactor (EFR), after major reductions in various elements of capital cost compared to earlier designs, was expected to have a capital cost in series production 20 to 30% higher than that of a comparable LWR (Refs. 45 and 48). Russia's minister of atomic energy recently acknowledged that "life has proved that a VVER-1000 reactor [a modern Russian LWR] is one-and-a-half times cheaper than a BN [fast neutron] reactor . . . [LWRs] are cheaper, safer, and economically more viable."[49]

Some FR designers argue, however, that recent developments would make it possible to build FRs at a cost no higher than that of LWRs (Ref. 50), and the Japanese FR program, among others, has set capital cost equality with LWRs as an explicit goal.[51,52] New FR concepts, such as lead-cooled and gas-cooled systems, are hoped by their advocates to have lower capital costs than traditional sodium-cooled FRs (Ref. 43). The economic features of these concepts remain undemonstrated, however, and new thermal reactors are hoped by *their* advocates to have significantly lower capital costs than traditional LWRs.

Recent estimates of the cost of LWRs cover a broad range. Those based on actual experience tend to be more than \$2000/kW(electric) (Ref. 53). Estimates for future construction from independent assessments are in the range of \$1500 to \$2000/kW(electric) (Refs. 15 and 54), while reactor vendors project overnight capital costs of \$1000 to \$1500/kW(electric) (Ref. 55). If the LWRs that would compete with future FRs had a capital cost of \$1500/kW(electric), a capital cost difference of \$0 to \$400/kW(electric) would correspond to a 0 to 27% premium for FRs—the high end comparable to that estimated in the most recently designed commercial systems and the low end representing success in efforts to equalize capital costs. Our range is substantially more generous to FRs than that adopted in the most recent NEA assessment, whose nominal estimate for future FRs was \$400/kW(electric) higher than future LWRs, with a range of \$150 to \$900/kW(electric) higher.[15]

As noted earlier, we used three different sets of assumptions about the financing for capital costs, corresponding to facilities owned by government, a regulated utility, and a private venture. Our financing assumptions are identical to those in Ref. 10 and result in fixed charge rates of 0.058, 0.123, and 0.208/yr, respectively. Construction time (which is assumed to be the same for both types of reactor) enters into the calculation due to the interest paid on capital during construction; we use a central value of 6 yr with a range of 3 to 9 yr and real average costs of money of 0.04, 0.064, and 0.139/yr for government, utility, and private venture, respectively. Finally, preoperating costs and contingency funds are usually proportional to capital cost; we have assumed central values equal to 10% of overnight capital cost for both preoperating costs and contingency funds, for both types of reactors, with a range of 5 to 15%.

III.C. Reprocessing and Fuel Fabrication Prices

The breakeven uranium price is also sensitive to the reprocessing price for FR fuel. For simplicity, we have chosen a central estimate for both the core and blanket fuel of \$1000/kg HM, with a range of \$500 to \$2000/kg HM—the same as for reprocessing LWR fuel. This is a generous assumption, as reprocessing costs for higher-burnup FR fuels with much higher plutonium content generally will be significantly higher. The recent NEA review, for example, posited a range of \$1000 to \$2000 to \$2500/kg HM for core fuel and \$900 to \$1500 to \$2500/kg HM for blanket fuel reprocessing (low-central-high values).[15] The \$500/kg HM lower bound of our range is intended to cover the possibility of substantial technological advance in the future. Our high value of \$2000/kg HM is by no means an upper bound on the price of FR reprocessing, but if reprocessing turns out to be more expensive, then there is little hope that uranium will reach the corresponding breakeven price in the foreseeable future.

We have assumed a central estimate for FR core fuel fabrication price of \$1500/kg HM, with a range of \$700 to \$2300/kg HM. As with reprocessing, this is the same as for MOX fuel fabrication price in the LWR recycling case. This also is generous because FR core fuel will have much higher plutonium content and design burnup, which generally implies a higher fabrication cost. This price range is approximately equal to that employed in the recent NEA analysis for FRs using MOX fuels.[15] For metal fuels, where the NEA study assumed minor actinides would also be recycled with the plutonium, they envisioned that core fuel fabrication would be more expensive (because of the extra cost of handling the more radioactive minor actinides), with a range of \$1400 to \$2600 to \$5000/kg HM.

We assume that the price of blanket fuel fabrication is about the same as the price of LEU fuel fabrication for LWRs—a central value of \$250/kg HM, with a range of \$150 to \$350/kg HM. This range appears again to be generous to the FR, as it is a factor of 2 lower than that used in the recent NEA assessment.[15]

Future FR systems, such as some of those envisioned in the Generation IV initiative, might involve substantially different fueling approaches, such as liquid fuels that would not require fabrication. Such approaches could have lower costs, but an accurate assessment will have to await further development of these technologies.

III.D. Other Prices and Parameters

We assume a central value of \$200/kg HM for the difference between the disposal cost for spent LWR fuel and for HLW resulting from the reprocessing of FR fuel, with a range of \$100 to \$300/kg HM. This is the same range used in Sec. II.C, which again is generous to FRs, as one would expect that HLW from higher-burnup FR core fuel would have higher activity and volume, increasing disposal costs. (This factor is compensated for, however, by the fact that we have chosen the same cost of disposal for wastes from reprocessing the blanket fuel, which will have low burnup, and the core fuel, which will have high burnup.)

We assume a nominal FR breeding ratio of 1.125, with a range of 1.0 to 1.25. Electricity price increases with breeding ratio in our model because more blanket material must be reprocessed each year. This result is an artifact of assigning a zero cost to the initial core fuel—and to excess plutonium produced by FRs. If start-up fuel was assigned a substantial value, then higher breeding ratios could be more economical (but, as explained earlier, FRs would be less competitive with once-through LWRs).

After the initial core and first reload, FRs would only require depleted uranium (DU) to replace uranium that fissioned, was transformed into plutonium, or was lost in processing. Many thousands of tons of DU already exist in the stored waste from uranium enrichment plants. As long as uranium demand is driven by LWRs, there will be little use for this DU, and its price will be low. We therefore assume a central DU price of \$6/kg U—the price of converting the material from uranium hexafluoride. However, once uranium prices increase to the point that FRs become competitive, those holding stocks of DU may begin to assign a significant value to it. When demand for uranium begins to be dominated by FRs and stocks of DU begin to be drawn down, the price of DU should approach the price of natural uranium because DU and natural uranium are almost perfect substitutes for use in breeder blankets. Even with such a high upper bound, DU price has virtually no effect on the economics of FRs.

IV. URANIUM PRICES AND RESOURCES

In the previous analysis we have calculated the breakeven uranium price—the price that would make reprocessing and recycling in LWRs or FRs economically competitive with LWRs operating on a once-through fuel cycle. In this section we review past and estimated future uranium prices, estimates of the amount of uranium that is ultimately recoverable at a given price, and scenarios of uranium consumption during the next century. We conclude that the uranium price will probably remain below the breakeven prices calculated in our previous reference cases for the next 100 yr and that reprocessing and recycling in both LWRs and FRs will remain uneconomic for the foreseeable future, barring dramatic reductions in the price of reprocessing and the fabrication of plutonium fuels, and, in the case of FRs, capital cost.

Figure 5 shows selected uranium prices during the last 30 yr. The real price paid by U.S. reactor operators (the weighted average of deliveries under long- and short-term contracts) fell from a high of \$190/kg U in 1982 to about \$28/kg U in 2002 (in 2003 dollars)[56]; prices in Europe were somewhat higher.[57] The spot market price for uranium has been considerably more volatile, falling from a high of \$300/kg U in 1977 to a low of \$20/kg U in 2000; the spot price of \$44/kg U in March 2004 was the highest in 15 yr and appeared still to be headed upward.[38]

The nuclear enthusiasm of the 1960s and 1970s, together with the rapid growth in electricity demand that was expected at that time, led utilities to order large numbers of reactors; expectations of a correspondingly rapid increase in uranium consumption led to the large price spike in the late 1970s. But the lower growth of electricity demand following the oil price shocks of the 1970s, coupled with the increase in nuclear costs and controversies following the Three Mile Island accident in 1979, led to the cancellation of most of these reactor orders, greatly reducing projected uranium demand and bringing the price back down. During much of the 1990s, world uranium production was well below world consumption, as governments and utilities reduced their inventories (because of their increased confidence in the availability of uranium when they needed it); this additional supply from inventory sales (including the U.S.-Russian HEU Purchase Agreement) reduced prices to a level below that necessary for production to equal consumption. In the last few years, however, there have been concerns about when these inventory supplies would run out and whether mine production could increase quickly enough to meet demand. As a result, uranium price has gone up significantly. Given the availability of large quantities of uranium recoverable (once the relevant mines are brought online) at prices in the range of \$40 to \$50/kg U, it appears unlikely that the price would rise above that level for any sustained period over the next few decades (though temporary fluctuations during periods

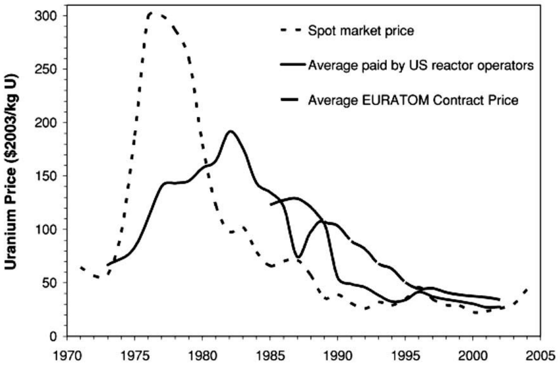

Fig. 5. Uranium prices from 1971 to 2004 (Refs. 38, 56, and 57).

when new mines have not yet come online to meet increased demand are likely).

Longer-term price predictions are notoriously difficult. Classical economic theory suggests that the price of nonrenewable resources should rise steadily over time, as the fixed available stock grows scarcer and more costly resources have to be used. But this model fails to take into account the ongoing discovery of additional resources and the development of improved technologies for identifying and extracting resources.[58] The amount of a mineral that can be recovered at a given cost of extraction can increase if technological improvements and discoveries of additional resources outpace the depletion of known deposits. This has, in fact, been the pattern throughout the last century for most minerals: Real prices have fallen even while rates of consumption have increased. The history of copper production is illustrative: As a result of improved technology, the real price declined by a factor of 3.8 from 1900 to 2000 despite a 25-fold increase in demand[59] and a decline in the average ore grade from 2 to 0.85% (Ref. 60). There is little reason to expect that uranium prices, which have been following a similar trend, will reverse course and begin increasing steadily until far more of the available resource has been consumed than will be the case in the next few decades.

The most commonly cited estimates of uranium resources are those in the "Red Book."[61] The 2001 Red Book estimates that total world "conventional" resources available at less than $130/kg U amount to 16.2 million tonnes U (the sum of "reasonably assured resources," "estimated additional resources," and "speculative resources"). If already-mined inventories are included, the total rises to 17.1 million tonnes U (Ref. 62). An international meeting sponsored by the International Atomic Energy Agency in 2000 concluded that total resources available in this category likely amount to 20 million tonnes U (Ref. 63).

Several points should be made about the Red Book estimates. First, many countries do not report resources in the lower-confidence and higher-cost categories. For example, Australia, which has some of the world's largest uranium resources, does not bother to estimate "speculative" resources because its better-characterized resources are so large already.

Second, this estimate is limited to "conventional" resources—that is, deposits where the uranium ore is rich enough to justify mining at the indicated price. In some cases, however, it may be attractive to produce uranium as a by-product. For example, ores with uranium concentrations as low as 4.5 ppm—less than twice the average abundance in the Earth's crust—have been recovered as by-products from copper mines, at costs of less than $50/kg U (Ref. 64). An additional 22 million tonnes U are estimated to be available in phosphate deposits worldwide (though at very low concentrations), and a significant fraction of this may ultimately be recovered as global demand for fertilizer continues to rise.

Third, low uranium prices over the last two decades virtually eliminated incentives for uranium exploration. Consequently, there are almost certainly large quantities of still-undiscovered uranium that are not included in the Red Book estimates—particularly in the higher-cost categories. Modest investments have led in recent years to dramatic increases in estimates of available resources. In early 2001, for example, the Canadian firm Cameco increased its estimate of the uranium available at its

McArthur River mine by more than 50% (Ref. 65). In short, despite the inclusion of "speculative resources" in the 17.1 million tonnes U figure, there is a very high probability that the amount of uranium that will ultimately prove recoverable at or below \$130/kg U will be significantly greater.

Another way to approach the problem is to estimate the shape of the supply curve as a function of price. Based on geologic relationships, which indicate that exponentially larger resources are available at lower ore grades, it seems likely that the relationship between price and resources is roughly exponential. According to one industry observer, "a doubling of price from present levels could be expected to create about a tenfold increase in measured resources."[66] If we assume, very conservatively, that the 2.1 million tonnes U of known resources reported in the 2001 Red Book as recoverable at \$40/kg U represent all resources that will ever be recoverable at that price, then the total uranium resource R (million tonnes uranium) recoverable at price p (dollars per kilogram of uranium) is given by

$$R = 2.1\left(\frac{p}{40}\right)^{\varepsilon} , \qquad (2)$$

where ε is the long-term price elasticity of supply. If a doubling of price leads to a tenfold increase in resources, $\varepsilon = 3.32$. By this crude estimate, more than 100 million tonnes U would be available at \$130/kg U. If the amount of uranium available at \$40/kg U is >2.1 million tonnes U, as seems very likely, then estimates of resource availability at higher prices would be proportionately greater as well.

One of the few serious attempts to estimate how much uranium is likely to be available worldwide concluded that a tenfold reduction in ore concentration is associated with a 300-fold increase in available resources.[67] If a doubling in price results in a tenfold increase in supply, this implies that a doubling in price would make economical the exploitation of ores with uranium concentrations 2.5 times lower. This seems plausible because not all extraction costs scale in direct proportion to the amount of ore mined and processed per ton of uranium recovered. If, at the other extreme, we assume that costs are inversely proportional to ore grade (as might be true at very low concentrations, when total costs became dominated by the amount of material mined and processed), then $\varepsilon = 2.48$, and ~40 million tonnes U would be available at \$130/kg U. More recently, the Generation IV Fuel Cycle Crosscut Group judged that ε might be as low as 2.35 (Ref. 16), which would give 34 million tonnes U available at \$130/kg U. Extrapolating to still higher prices, 170 to 500 million tonnes U would be available at \$260/kg U. These estimates are summarized in Table VI.

At the extreme of low-grade resources is the 4500 million tonnes U dissolved in the world's oceans at a concentration of 3 ppb. The recovery of this uranium has been demonstrated using adsorbents. Early approaches involved pumping seawater through the adsorbent; a pilot plant operated in Japan for 2 yr, but the pumping required more energy than would be provided by the recovered uranium, and this approach was abandoned.[68] More recent approaches rely on ocean currents to move seawater through fixed arrays of adsorbents, with a ship collecting the uranium-bearing adsorbents for onboard processing or delivery to a shore-based processing facility. Rough cost estimates have varied from \$100/kg U to more than \$1000/kg U; the 2001 Red Book chose \$300/kg U as representative of current thinking. If uranium could be recovered from seawater at costs below the breakeven cost for reprocessing and recycling, the use of plutonium fuels could be deferred for many centuries.

Setting aside the question of seawater uranium, if the previous estimates of terrestrial resource availability are matched to estimates of future uranium consumption on a once-through fuel cycle, it is clear that uranium prices will not rise anywhere close to our central estimates of the breakeven price for reprocessing and recycling in LWRs or FRs for many decades to come. In a study of future energy scenarios in 1998, the World Energy Council and the International Institute for Applied Systems Analysis outlined six scenarios for future energy supply, covering a wide range of assumptions about population and economic growth,

TABLE VI

Estimates of Uranium Resources Ultimately Recoverable at \$80, \$130, and \$260/kg U, Assuming 2.1 million tonnes U Ultimately Recoverable at \$40/kg U

Source	Long-term Elasticity of Supply, ϵ	R (million tonnes uranium) for p less than or equal to		
		\$80/kg U	\$130/kg U	\$260/kg U
Uranium Information Centre[66]	3.32	21	105	500
Deffeyes and MacGregor[67]	2.48	12	40	220
Generation IV group[16]	2.35	11	34	170

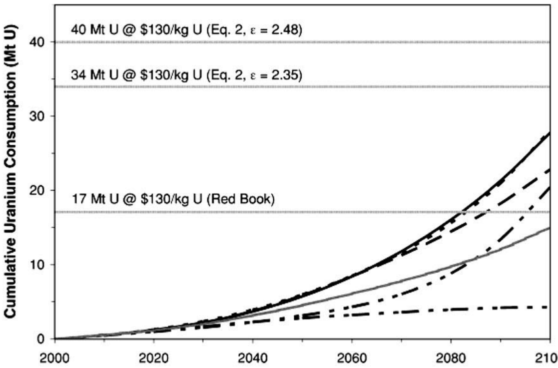

Fig. 6. Scenarios of cumulative uranium consumption, assuming a once-through fuel cycle with an average uranium requirement of 19 tonnes U/TW·h, and estimates of ultimately recoverable uranium resources at $130/kg U. Scenarios of nuclear electricity production taken from Ref. 69, normalized to 2434 TW·h in 2000.

resources, and technology.[69] Figure 6 shows cumulative uranium consumption in these scenarios, assuming that nuclear electricity is produced entirely by LWRs operating on a once-through cycle with an average uranium requirement of 19 tonnes U/TW·h.[f] Also shown are estimates of uranium resources available at prices of $130/kg U or less. Based on these scenarios, it seems very likely that uranium resources will continue to be available at substantially below the breakeven price for reprocessing at $1000/kg HM throughout the 21st century.

V. IMPACT ON REPOSITORY REQUIREMENTS

In recent years, some have argued that repository space is the most pressing constraint on the expansion of nuclear power. This argument is one of the principal drivers of the U.S. Advanced Nuclear Fuel Cycle Initiative. The DOE argues that existing U.S. reactors, discharging nearly 2000 tonnes HM/yr of spent fuel, will fill the 63 000 tonnes HM legislative capacity limit for the Yucca Mountain repository by 2015 and the "theoretical maximum" capacity of 120 000 tonnes HM by ~2050 (if the current level of nuclear capacity were retained).[70] Reprocessing the fuel and separating and transmuting the heat-generating radionuclides, it is argued, could make a second repository unnecessary, even if U.S. nuclear energy generation grows substantially in the future.

Several points should be made concerning this argument. First, it applies only to the United States. Only the United States has chosen a repository site with fixed boundaries, whose capacity cannot be increased indefinitely by digging more tunnels. Other countries are examining sites in huge areas of rock, clay, or salt, where the waste from centuries of nuclear electricity generation could be emplaced at a single site.

Second, traditional approaches to reprocessing and recycling do not lead to reductions in the amount of repository space required per unit of electricity generated. As discussed earlier, the required repository volume is determined by heat output of the wastes, and if plutonium is recycled in existing LWRs, the resulting buildup of heat-generating minor actinides means that the total waste heat per unit of electricity generated is higher than for direct disposal of spent nuclear fuel. To avoid the need for an additional U.S. repository, it would be necessary to separate, recycle as fuel, and transmute all the major long-lived heat-generating radionuclides. If we assume, as recent international reviews do, a higher reprocessing cost for these kinds of separations than the central

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[f] Assumes an average burnup of 50 MWd/kg HM, a net efficiency of 35%, and fuel enrichment and tails assays of 4.2 and 0.2% ^{235}U. [A tails assay of 0.2% would minimize cost when uranium price is ~1.3 times enrichment price (e.g., $130/kg U for $100/SWU).] The use of higher burnups, lower tails assays, and other reactor systems could reduce uranium consumption in a once-through cycle to as little as 12 tonnes U/TW·h (e.g., a pebble-bed reactor with burnup of 100 MWd/kg HM, an efficiency of 46%, and enrichment and tails assays of 8 and 0.1%).

estimate for traditional reprocessing used in the text, a higher fabrication cost (given the need for remote handling) for the fuel, and a transmutation reactor or accelerator capital cost \$200/kW(electric) higher than that of comparably advanced once-through systems, then separations and transmutation would not be economic until the cost of spent-fuel disposal reached some \$3000/kg HM, nearly ten times current estimates.[6]

Third, the argument is based on the assumption that it would be less difficult to gain public acceptance and licensing approval for complex and expensive spent-fuel separation and transmutation facilities than for a second repository. This assumption is likely wrong. Reprocessing of spent fuel has been fiercely opposed by a substantial section of the interested public in the United States for decades. The health and safety risks to current generations from a separations and transmutation approach would be greater than those associated with direct geologic disposal of spent fuel.

Fourth, the argument is also based on the assumption that, many decades in the future when repository space has become scarce and reactor operators are willing to pay a significant price for it, it will still not be possible to ship spent fuel from one country to another for disposal. If, in fact, repository capacity does become scarce in the future, reactor operators will likely be willing to pay a price for spent-fuel disposal well above the cost of providing the service. It seems likely that if the willingness to pay gets high enough, the opportunity for profit will motivate some country with an indefinitely expandable repository to overcome the political obstacles that have blocked international storage and disposal of spent fuel in the past.

Premature decisions based on early estimates of unproven technology can be very costly. Given the availability of proven, low-cost dry-cask storage technology that can store spent fuel safely for decades, there is no rush to resolve these debates.

VI. CONCLUSIONS

At a reprocessing price of \$1000/kg HM and with our other central estimates for the key fuel cycle parameters, reprocessing and recycling plutonium in existing LWRs will be more expensive than direct disposal of spent fuel until the uranium price reaches more than \$370/kg U—a price that is not likely to be seen for many decades, if then.

At a uranium price of \$50/kg U (somewhat higher than current prices), reprocessing and recycling at a reprocessing price of \$1000/kg HM would increase the cost of nuclear electricity by 1.3 mill/kW·h. Since the total back-end cost for the direct disposal is in the range of 1.5 mill/kW·h, this represents more than an 80% increase in the costs attributable to spent-fuel management (after taking account of appropriate credits or charges for recovered plutonium and uranium from reprocessing).

These figures for the breakeven uranium price and the contribution to the cost of electricity are conservative. The central estimate of the reprocessing price, \$1000/kg HM, is substantially below the cost that would pertain in privately financed facilities with costs and capacities identical to the large (and largely not privately financed) commercial facilities now in operation. The central estimate of the MOX fuel fabrication price, \$1500/kg HM, is significantly below the price actually offered to most utilities in the 1980s and 1990s. No charges were included for storage of separated plutonium or removal of americium, or for additional security, licensing, or shutdown expenses for the use of plutonium fuels in existing reactors. A full charge for 40 yr of interim storage in dry casks was included for all fuel going to direct disposal even though new reactors are being built with storage capacity for their lifetime fuel generation. The costs of geological disposal of spent MOX fuel were assumed to be equal to that of spent LEU fuel despite the substantially higher heat output of spent MOX fuel.

Reprocessing and recycling plutonium in FRs with an additional capital cost of \$200/kW(electric) compared to new LWRs will not be economically competitive with a once-through cycle in LWRs until the price of uranium reaches some \$340/kg U, given our central estimates of the other parameters. Even if the capital cost of new FRs could be reduced to equal that of new LWRs, recycling in FRs would not be economic until the uranium price reached \$140/kg U.

At a uranium price of \$50/kg U, electricity from a plutonium-recycling FR with an additional capital cost of \$200/kW(electric), and with our central estimates of the other parameters, would cost more than 7 mill/kW·h more than electricity from a once-through LWR. Even if the additional capital cost could be eliminated, the extra electricity cost would be more than 2 mill/kW·h.

As with reprocessing and recycling in LWRs, these estimates are conservative. We have assumed no cost for start-up plutonium, no additional cost for reprocessing or fabricating higher-plutonium-content FR fuel (compared to LWR fuel), and no additional operations and maintenance costs for FRs compared to LWRs. Costs for the more complex chemical separation processes and more difficult fuel fabrication processes needed for more complete separation and transmutation of nuclear wastes have been estimated in recent studies to be substantially higher than those estimated here for traditional reprocessing and recycling. The extra electricity cost would be even higher if these approaches were pursued.

World resources of uranium likely to be economically recoverable in future decades at prices below the breakeven uranium price amount to several tens or even hundreds of millions of tons, enough to fuel a growing nuclear enterprise using a once-through fuel cycle throughout the century.

Limits on repository space are not a persuasive reason to pursue reprocessing. Traditional approaches to reprocessing and recycling would not help, in any case; a complex of separations and transmutation facilities would be necessary. It is unlikely to be easier to gain approval and acceptance for building separation and transmutation facilities rather than for repository expansion or building a new repository. Reactor operators probably would be willing to pay substantially more for direct disposal of spent fuel in order to avoid expensive separation and transmutation, which would increase incentives for states or other countries to accept the spent fuel.

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REFERENCES

1. J.-M. CHARPIN, B. DESSUS, and R. PELLAT, “Economic Forecast Study of the Nuclear Power Option,” Office of the Prime Minister, Paris, France (July 2000).

2. *The Economics of the Nuclear Fuel Cycle*, Organization for Economic Cooperation and Development, Nuclear Energy Agency, Paris, France (1994).

3. I. HENSING and W. SCHULZ, *An Economic Comparison of Different Disposal Methods Used by Nuclear Power Plants: A Cost Simulation of Alternative Strategies from the German Point of View*, Oldenbourg-Verlag, Munich, Germany (1995).

4. J. LAKE, “Outdated Thinking is Holding Us Back,” *Washington Post*, May 12, 2001.

5. “FY 2004 Detailed Budget Justifications—Office of Nuclear Energy, Science, and Technology,” U.S. Department of Energy (Feb. 2003).

6. M. BUNN, S. FETTER, J. HOLDREN, and B. VAN DER ZWAAN, “The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel,” Harvard University Managing the Atom Project, Cambridge, Massachusetts (2003).

7. S. FETTER, University of Maryland School of Public Policy; available on the Internet at ⟨http://www.puaf.umd.edu/fetter⟩.

8. “The Economic and Commercial Justification for THORP,” British Nuclear Fuels Limited (1993).

9. A. MACLACHLAN, “BNFL, Overseas Customers Agree on New Reprocessing Contract Terms,” *Nucl. Fuel* (Oct. 15, 2001).

10. *Nuclear Wastes: Technologies for Separations and Transmutation*, U.S. National Research Council, Committee on Separations Technology and Transmutation Systems, National Academy Press, Washington, D.C. (1996).

11. “Nuke Fuel Reprocessing to Cost 15 Trillion Yen,” *Japan Economic Newswire* (May 15, 2003).

12. M. HIBBS, “More Downward Pressure Expected by Germans on Reprocessing Price,” *Nucl. Fuel* (Feb. 9, 1998).

13. G. VARLEY and D. COLLIER, “Fuel Cycle Cost Data,” Nuclear Assurance Corporation (Oct. 1999).

14. C. BATAILLE and R. GALLEY, *The Back End of the Fuel Cycle: Part I: General Study*, Office Parlementaire d’Evaluation des Choix Scientifiques et Technologiques, Paris, France (June 1998).

15. “Accelerator-Driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles: A Comparative Study,” OECD/NEA 03109, Organization for Economic Cooperation and Development, Nuclear Energy Agency (2002).

16. *Generation IV Roadmap: Report of the Fuel Cycle Crosscut Group*, U.S. Department of Energy, Office of Nuclear Energy, Washington, D.C. (Mar. 2001).

17. *The Cost of High-Level Waste Disposal in Geologic Repositories*, Organization for Economic Cooperation and Development, Nuclear Energy Agency, Paris, France (1993).

18. “Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program,” DOE/RW-0533, U.S. Department of Energy, Office of Civilian Radioactive Waste Management (May 2001).

19. “Nuclear Waste Fund Fee Adequacy: An Assessment,” DOE/RW-0534, U.S. Department of Energy, Office of Civilian Radioactive Waste Management (May 2001).

20. S. MATSUURA, “Analysis of the History of Cost Evaluation of High-Level Radioactive Waste Disposal,” Harvard University Managing the Atom Project, Cambridge, Massachusetts (unpublished) (2003).

21. “Scoping Assessment of Implications of Reprocessing Scenarios for Disposal Options: Paper to RWMAC,” NIREX Doc. 334004, Nirex Limited (May 2000).

22. NIREX, “Response to Questions Raised Based on Reference 334004,” Letter to MIKE SADNICKI (Nov. 22, 2000).

23. J. KANG, Princeton University, Personal Communication (May 2003).

24. B. G. CHOW and G. S. JONES, "Managing Wastes With and Without Plutonium Separation," Report P-8035, RAND Corporation (1999).

25. *Radioactive Substances Act 1993: Document Containing the Agency's Proposed Decision on the Justification for the Plutonium Commissioning and Full Operation of the Mixed Oxide Fuel Plant*, United Kingdom Environment Agency, London, United Kingdom (Oct. 1998).

26. M. HIBBS, "Utilities End Hanau MOX Support; Bonn Now Angling for Russian Pu," *Nucl. Fuel* (July 6, 1995).

27. *Management and Disposition of Excess Weapons Plutonium: Reactor Related Options*, National Academy of Sciences, Panel on Reactor-Related Options, National Academy Press, Washington, D.C. (1995).

28. "Report to Congress: Disposition of Surplus Defense Plutonium at Savannah River Site," National Nuclear Security Administration, Office of Fissile Materials Disposition (Feb. 15, 2002).

29. M. SADNICKI, F. BARKER, and G. MacKERRON, "Re-Examination of the Economic Case for the Sellafield MOX Plant," Science Policy Research Unit, Sussex University, Brighton, United Kingdom (May 2000).

30. N. MOTE, "The Commercial Use of Mixed-Oxide Fuel in Light-Water Reactors," presented at U.S. Department of Energy-RF Ministry of Atomic Energy Experts Workshop: Costing Methodologies for Economic Evaluation of Utilization Options of Weapons Plutonium from Defense Programs in the Course of Nuclear Disarmament, Obninsk, Russia, May 12–14, 1999.

31. A. MacLACHLAN, "EDF Makes Case for Economic Advantage of Reprocessing over Interim Storage," *Nucl. Fuel* (Oct. 7, 1996).

32. M. HIBBS, "Court Says Hesse Must Pay Siemens for Costs of Shutting MOX Plant," *Nucl. Fuel* (Apr. 26, 1993).

33. "Report to Congress on the Projected Life-Cycle Costs of the U.S. and Russian Fissile Materials Disposition Programs," U.S. National Nuclear Security Administration, Office of Fissile Materials Disposition (Mar. 30, 2001).

34. "CRWMS Modular Design Construction and Operation Options Report," DOE/OCRWM, U.S. Department of Energy, Office of Civilian Radioactive Waste Management (Dec. 1998).

35. E. M. SUPKO, "Minimizing Risks Associated with Post-Shutdown Spent Fuel Storage and LLW Disposal," presented at the Infocast Nuclear Power in the Competitive Era postconference workshop, Developing Risk Strategies for Successful Decommissioning, Washington, D.C., Jan. 30, 1998.

36. "Toward Implementation of Interim Storage for Recycled Fuel Resources," Interim Report of the Nuclear Energy Working Group, Advisory Committee for Energy, Agency of Natural Resources and Energy, Ministry of Trade and Industry, Tokyo, Japan (June 11, 1998).

37. T. L. NEFF, "Decision Time for the HEU Deal," *Arms Control Today*, **31**, *5* (June 2001).

38. UX CONSULTING, available on the Internet at ⟨http://www.uxc.com⟩.

39. M. KNAPIK, "LES Hires Advisers to Prime Renewed Push to Site Tennessee Plant; PACE Slams USEC," *Nucl. Fuel* (May 26, 2003).

40. "Trends in the Nuclear Fuel Cycle: Economic, Environmental, and Social Aspects," OECD/NEA 03030, Organization for Economic Cooperation and Development, Nuclear Energy Agency (2002).

41. C. K. ANDERSON, "Developments in the U.S. and European LWR Fabrication Markets: A 1998 Update," *Proc. Uranium Institute: 23rd Annual Symp.*, London, United Kingdom, September 10–11, 1998.

42. W. HENI, "Evaluation of Direct Disposal from the Point of View of One Utility and Perspectives for Waste Management," *Nucl. Technol.*, **121**, 120 (1998).

43. "A Technology Roadmap for Generation IV Nuclear Energy Systems," U.S. Department of Energy, Nuclear Energy Research Advisory Committee, and Generation IV International Forum (Dec. 2002).

44. J. G. DELENE, J. SHEFFIELD, K. A. WILLIAMS, R. L. REID, and S. HADLEY, "An Assessment of the Economics of Future Electric Power Generation Options and the Implications for Fusion," ORNL TM-1999-243, Oak Ridge National Laboratory (1999).

45. J. P. CRETTE, "Review of the Western European Breeder Programs," *Energy*, **23**, *7–8*, 581 (1998).

46. J. G. DELENE, L. C. FULLER, and C. R. HUDSON, "ALMR Deployment Economic Analysis," ORNL TM-12344, Oak Ridge National Laboratory (1993).

47. Y. I. CHANG and C. E. TILL, "Economic Prospects of the Integral Fast Reactor (IFR) Fuel Cycle" (unpublished) (1991).

48. J. C. LEFEVRE, "European Fast Reactor 98: Outcome of Design Studies," EFR Associates (1998).

49. S. SAVENKOV, "Minister Rumiantsev: Minatom Will Not be Privatized," (Interview), Apr. 4, 2003 (translated by the U.S. Department of Energy).

50. C. E. BOARDMAN, M. HUI, G. CARROLL, and A. E. DUBBERLEY, "Economic Assessment of S-PRISM Including Development and Generating Costs," General Electric Nuclear Energy.

51. H. NODA and T. INAGAKI, "Feasibility Study on Commercialized FR Cycle Systems in Japan—The Results in the

First Phase and Future Plans of the Study," presented at Global 2001: The Back End of the Fuel Cycle—From Research to Solutions, Paris, France, September 9–13, 2001.

52. K. AIZAWA, Japan Nuclear Cycle Development Institute, "Feasibility Studies on Commercialized FR Cycle System," presented at Aomori, Japan, July 22, 2000.

53. J. M. DEUTCH and E. J. MONIZ, "The Future of Nuclear Power: An Interdisciplinary MIT Study," Massachusetts Institute of Technology (July 2003).

54. "Assumptions to the Annual Energy Outlook 2004," DOE/EIA-0554, U.S. Department of Energy, Energy Information Administration (Feb. 2004).

55. "Technical Assessment Guide: Volume 3, Revision 8: Fundamentals and Methods—Electricity Supply," TR-100281-V3R8, Electric Power Research Institute (1999).

56. "Uranium Industry Annual 2002," DOE/EIA-0478, U.S. Department of Energy, Energy Information Administration (May 2003).

57. "Annual Report 2002," Euratom Supply Agency (2003).

58. M. A. ADELMAN, "My Education in Mineral (Especially Oil) Economics," *Annu. Rev. Energy Environ.*, **22** (1997).

59. K. E. PORTER and D. L. EDELSTEIN, "Copper Statistics," Open-File Report 01-006, U.S. Geological Survey (Aug. 28, 2002).

60. O. GROENVELD, "The Technology Environment for the 21st Century—The Mining Industry," presented at Technology—Australia's Future: New Technology for Traditional Industries, Melbourne, Australia, Nov. 1998.

61. *Uranium 2001: Resources, Production, and Demand*, Organization for Economic Cooperation and Development, Nuclear Energy Agency, Paris, France (2002).

62. R. PRICE and J. R. BLAISE, "Nuclear Fuel Resources: Enough to Last?" *NEA News*, *20.2* (2002).

63. "International Symposium Concluded that Uranium Supply for Nuclear Power is Secure," press release 2000/26, International Atomic Energy Agency (Oct. 6, 2000).

64. T. C. POOL, "Uranium Resources for Long-Term, Large-Scale Nuclear Power Requirements," *Nonrenewable Resour.*, **3**, *4* (1994).

65. "Cameco Increases McArthur River Uranium Reserves," press release, Cameco (Jan. 25, 2001).

66. I. HORE-LACY, *Nuclear Electricity*, 7th ed., Uranium Information Centre, Ltd., Melbourne, Australia (2003).

67. K. S. DEFFEYES and I. D. MacGREGOR, "World Uranium Resources," *Sci. Am.* (Jan. 1980).

68. T. KATO, K. OKUGAWA, Y. SUGIHARA, and T. MATSUMURA, "Conceptual Design of Uranium Recovery Plant from Seawater," *J. Therm. Nucl. Power Eng. Soc.*, **50** (1999) (in Japanese).

69. *Global Energy Perspectives*, N. NAKICENOVIC, A. GRÜBLER, and A. McDONALD, Eds., Cambridge University Press, Cambridge, United Kingdom (1998).

70. "Report to Congress on Advanced Fuel Cycle Initiative: The Future Path for Advanced Spent Fuel Treatment and Transmutation Research," U.S. Department of Energy, Office of Nuclear Energy, Science, and Technology (Jan. 2003).

Chairwoman BIGGERT. Without objection.

Mr. HONDA. Thank you.

Dr. HAGENGRUBER. Yeah, a very interesting question to be done with an answer to be compact. Unfortunately, I am the age where I started more than 35 years ago, my first study was to look at long-term and short-term technical approaches to nuclear waste. The reactors cost $1 billion at the time. There wasn't a Three Mile Island. There wasn't a study on it, and there wasn't a Carter decision on reprocessing. And it seems like I have seen all of this before. We knew how to reprocess material in a way that produced the closed fuel cycle. We knew what the nuclear waste issues were, including interim storage as a very attractive option. We had lots of technical opportunities that were demonstrated up in Idaho and other places and Hanford for how to dispose the material, maybe not as good as today, but it is hard to see the last 30 years as having made that much progress.

The issue, in the end, wasn't the cost of nuclear power and the issue of interest rates and—I mean, West Valley was built and then shut down not—in part not because the technology failed, but the basic decision of the infrastructure and the supporting infrastructure had a hole in it. The hole is that proliferation became an increasing concern, not just because it was President Carter. It was a national concern. There were the London Suppliers Group and other people got together, and decisions were struggled with, not consensus, to decide whether or not to reprocess in order to have this plutonium appear as an economy, whether it was in the United States. Whatever we did, the world would, in fact, eventually do. And today, even after all of these years of being out of the business, the world still waits for us to make the decision on Generation IV, to make the decisions on reprocessing, to make the decisions on Yucca Mountain. I mean, with all deference to France and the other countries making these choices, people are looking to us for leadership in the future of nuclear energy.

Our position at APS and the position that is not in controversy with anything that has been said here, the technical information about the processes, the work of the Department in trying to pursue it, Matt's comments about it, I mean, we all—we would agree with many of these. We represent 44,000 physicists, and you can probably not get two of them to have the same opinion on anything. But where they divide on the business of plutonium is simple. They believe that if this plutonium appears in the economy, one group believes that it is so unattractive that it will never be made into a weapon. The other group believes that it is explosive. From a physics point of view, interestingly enough, they are both absolutely right. You could make it into an explosive. On the other hand, no country sophisticated enough to do that, in my judgment, would ever choose to use that material for a weapons program. But we face the important decision, and you face the decision, that we can make all of the technical decisions about waste and reprocessing, and there will be good decisions. The Department of Energy will do good research, and laboratories like Argonne will provide good technologies. But if you wish to avoid another West Valley, if you wish to have a robust leadership of nuclear energy that will last for 30 or 40 years, the issue of proliferation has got to be central in the decision about whether to go forward. And these technologies not only have to be robust, there has to be a consensus in this country that they are, because what we do, the rest of the world will take as leadership. Thank you.

Dr. FINCK. Yes, I want to make five comments. And the first one is one of the most important one. And Madame Chairwoman made the right comment that we need to have a systems look at this issue. If when you look at the trees, we will forget to look at the forest. And the "forest" here is our future. The future where we need to have energy sources. We need to have a total look and integrate a nuclear energy system that needs to deal with its waste, needs to deal with its resources.

And my second comment is about—is to Mr. Bunn about the UREX+ technology. The UREX+ can actually lure you to do a co-separation of all of the transuranics. When we talk about proliferation resistance, we should actually not concentrate on what the separation technology is, but on where the recycle technology is for the following reasons. Thermal reactors for physics reasons need relatively pure products. You can not recycle fission products in thermal reactors, for example. Therefore, it is difficult to put dirty products, or proliferation-resistant products, back in a thermal reactor. The first reactor—pure physics reasons that we cannot change—can take much dirtier product. So the issue of proliferation resistance should be put on the level of what reactors you want to use, what spectrum we are going to use. I mean, it is a real physics question.

My third comment is on safeguards, and I absolutely agree with what Dr. Hagengruber has been saying. We are at a stage where we today can make major impacts on what we are doing with new technologies having developed new computing technologies, new modeling capabilities, and we can really change the future drastically there to avoid any risk of diversion of misuse of any plant.

Comment number four on economics. Again, we should not look at a tree. We need to look at the forest. We need to do a full life cycle analysis for the economics of the nuclear system. The disposal part of the disposal component of the nuclear fuel cycle is only a few percent, changing the cost of a few percent by even 50 percent might not be that important in view of the benefits we can get out of that change.

Lastly, a comment on research and development. I think this country in the last four or five years, I have been here about eight years, and we have made major progress in nuclear R&D. We have basically come from a place where there was not much going to a place where we can be the leaders of the world. But the objective here is not to be a leader of the world in R&D. The objective, to me, is very different. We are going to need nuclear power, because we are going to need clean energy. Global warming is probably a very major concern. Energy security is a concern. We are going to need to build these reactors. What I would like, personally, is to build them with U.S. technology in U.S. plants by creating high-tech U.S. jobs. It is important that we do this R&D so that the plants are fabricated here and we don't import them from elsewhere.

Thank you.

Chairwoman BIGGERT. Thank you. Thank you very much.

And I will recognize myself for five minutes.

Dr. Finck's testimony points out that the technology decisions link to reactor design and fuel cell choices. How is the Department coordinating a decision on reprocessing with the decisions for a next generation nuclear plant design, transmutation, technology, and overall fuel cycle choices? Are you working with industry on these choices?

Mr. JOHNSON. Thank you. With respect to the future and the linkage between our advanced reactor technology development program and our advanced fuel cycle program, those two programs are actually very much intertwined where we have laboratory personnel across the complex working cooperatively across laboratory boundaries with one another, such as Argonne, Idaho, Los Alamos working together. The decisions that we are making with respect to the Generation IV reactor technologies, those decisions are being made in the context of the fuel technologies and recycle technologies that are being investigated or are under investigation within the advanced fuel cycle program. So it is very much a very well integrated activity. We are working in the Generation IV program on an international basis so that it also brings in our international laboratory partners in France, Japan, and others. So the decisions—it is, at this point, very early in the Generation IV reactor development, actually the fuels program, I believe rightly so, is leading the reactor development, trying to look at what type of reactor fuels are best for getting to the key issues of minimization of waste generation, maximizing the transmutation of the various waste products within an existing fuel cycle for a Generation IV program. We have much work left to do, don't get me wrong, but the—with respect to the execution of the Department's advanced reactor and fuel cycle program, it is highly integrated from top to bottom, both in the federal staff, laboratory staff. You asked with respect to the industry participation, we probably do not have as much industry participation as we could. The commercial industry today is focused on the near-term deployment, looking through our Nuclear Power 2010 program getting plants built in the next, you know, five- to 10-year time frame whereas the work we are doing in our advanced fuel cycle engine programs are longer-term looking 20 to 30 years out.

Thank you.

Chairwoman BIGGERT. One of the big differences, it seemed like, in particularly, France where the—it is a government subsidy, really, to operate these plants, which is a big difference than we have in the United States.

Mr. JOHNSON. Yes, ma'am.

Chairwoman BIGGERT. Then Dr. Finck, how long would it take Argonne or another DOE lab to develop a detailed engineering system of the fuel cycle, including the economics, the waste, proliferation-resistant, and general safety and security characteristics? I mean, is anyone working on such a model now?

Dr. FINCK. Yes. We are actually working in collaboration with all of other labs, including Idaho, Los Alamos, Oak Ridge, I think, yes, on the systems analysis. And I think we have been doing this for, now, three years in an integrated manner. We have made a lot of progress where I would say by 2007, which is a deadline that comes up often, and even maybe before, we already have many of the technical answers. I think we are in the stage of integrating them and we look at the systems. And so 2007 seems to me with a focused effort to be absolutely reachable.

Chairwoman BIGGERT. Well, I seem to recall, since I have been on this committee and since I have been in Congress, that you have been working on EMT and pyroprocessing and things that it seems like it is not something new that has just come up this year that we are planning on doing.

Dr. FINCK. Yes, indeed. Many of the technologies we have put through these systems are relatively mature and the technical answers are well understood.

Chairwoman BIGGERT. Yeah, and it is true that France is really operating on a system that really was developed years and years ago. Is it 30 years or so that——

Dr. FINCK. Well, I think the PUREX technology was first published integrally in 1957. I mean, this is a well-known technology, which is quite accessible. I think the book was published in 1957, if I recall. So they are using many of the technologies—actually U.S. technologies that we exploited——

Chairwoman BIGGERT. That is what they told us that they have gotten them from——

Dr. FINCK. These are extremely well known, and then they improved them after—of course, after they acquired them. For example, one of the big improvements is to reduce the volume of waste by a factor of about four in the last 10 or 15 years. So there have been major incremental changes, but the basis is roughly the same. Yes.

Chairwoman BIGGERT. And then are the safeguards in monitoring research and development part of Argonne's research program?

Dr. FINCK. We do very little bit of it. I think the places that have real expertise would be places like Los Alamos. But I think what is important is to integrate the research we do on separations and reactors with the research done in other labs. If we run these research programs in parallel, we have had good discussion with—certainly with integration. I think here is key.

Chairwoman BIGGERT. Thank you very much.

My time has expired.

And I will recognize Mr. Matheson from Utah for five minutes.

Mr. MATHESON. Thank you, Madame Chairwoman.

Mr. Johnson, in your testimony on page four, you state that a commercial scale-up of spent fuel technologies could be accomplished relatively rapidly if existing domestic facilities could be modified and used. What—which facilities were you talking about in terms of where are they and who owns those facilities?

Mr. JOHNSON. I apologize. I am not able to recall the exact three locations. I would be more than happy to answer that question in writing, but off the top of my head, I don't want to give you the wrong answer.

Mr. MATHESON. No, that is okay. All right.

How—when you look at how DOE is looking at selecting a reprocessing technology, you know, this is coming back on Mr.

Honda's line of questioning a little bit in terms of as we move forward, the direction you have been given now, do we need to change the policy direction we have given you as Congress in terms of how you are going about your research and development in terms of looking at developing new technologies? What do you think? Do you need more flexibility? Do you need more direction? Or are you happy with the current circumstance?

Mr. JOHNSON. I believe we are very happy with the current policy and direction that we have. We have tried to lay out a reasoned, logical process for stepping through various laboratory investigations in stepping, again, through looking at what technologies, whether it is a UREX+ type process, whether it is a crystallization process, a volatilization process. So there are—we do have several processes that have been—being investigated at the laboratory scale. Again, it just takes some time to take and develop these technologies, refine them in the laboratory, and then make decisions based on the technical data that has generated in moving and making a selection to move up a technology into a larger scale experiment. So what—one thing we are trying to do is to walk through the investigation of the issues and the potential treatment technologies and then make a sound technical decision of how we take those from the smallest investigation in the laboratory scale and scale-up the technologies to whether it is the next step up, an engineering scale, and that what would ultimately be used as the basis for a decision to move forward for a commercial-scale application. I mean, for example, we are currently looking at spent fuel on the order of kilograms of spent fuel material in the laboratory that if you did it for a year, it would be—but what we are talking about in a commercial scale would be, you know, thousands of metric tons. So we are—very small-scale work going on right now.

Mr. MATHESON. In your testimony, you also said the development of advanced fuel treatment technologies would improve repository capacity. Do you have an estimate of how much repository capacity would be increased under the different reprocessing options you are looking at right now?

Mr. JOHNSON. An exact number, no. The—for example, uranium constitutes about 90 percent—96 percent of the mass in commercial spent fuel. So the—a process such as a UREX+ process that would take out the uranium would see a resulting reduction in the mass of heavy metal needing to go into a repository by an equivalent amount. But we are talking—but the issue in the repository isn't just volume. It is a heat generation. It is——

Mr. MATHESON. Right.

Mr. JOHNSON. There are other constituents in the spent fuel, both in near-term, such as strontium, which is really a near-term heat issue, and then the longer-term heat issue associated with americium. So it is really the—it is a complex problem, multi-faceted. It is both a volume issue as well as a heat-generation issue. And the heat-generation issue, I believe, as Dr. Finck said, if really addressed, by taking it from the next step of the reprocessing and then the destruction of these higher actinides in a fast reactor system.

Mr. MATHESON. Thanks.

I yield back, Madame Chairman.

Chairwoman BIGGERT. Thank you.

Now we will hear from our resident—one of our resident physicists, Mr. Bartlett, for five minutes.

Mr. BARTLETT. I am a physiologist rather than a physicist. The physicist is sitting to my right.

I get very different estimates as to the world's supply of economically recoverable fuel for light wire reactors. Could each of you tell me, in terms of years at present use rates, what you understand that supply to be? It is not infinite.

Mr. JOHNSON. No, sir, it is not infinite, as all our resources are not necessarily infinite. There have been some studies that have been produced, both within the Department and outside of the Department, and as you can imagine, they come up with different numbers. Those numbers have gone—range anywhere from—there is, you know, a 50- to 100-year supply of uranium around the globe to the fact that, you know, there is a 1,000-year supply. So there really is no firm, strong agreement with respect to the energy resources available in the uranium ore around the globe, but the range—again, the range is anywhere from, you know, 50 to 100 years to 1,000 years.

Mr. BARTLETT. Mr. Bunn.

Mr. BUNN. Yes, this—we have—in the Harvard study that I mentioned, there is an extensive appendix on this subject. The range of estimates comes from, I think, in part, differences of understanding of the terms by which the estimates are described. Very often, people refer to reserves, which is a term really used to describe, basically, uranium that you have actually struck a pick to, as though that were all of the uranium in the world, as opposed to resources, which is the amount of uranium that might be available in the future as technology develops and more uranium is found and so on. The reality is, because of, until very recently, very low prices for decades for uranium, there has been very little searching for uranium, particularly at higher prices than existed for the last couple of decades. And as a result, it seems certain to those who have looked at it in detail, I think, that there is a lot more uranium out there than is currently reported as reserves.

Mr. BARTLETT. What is currently reported as reserves?

Mr. BUNN. Currently, the—let us see. The red book, which is the IAE document, suggests that there is something of the order of several million tons that are—there is basically 17.1 million tons of uranium available at prices in the range of $40 to $80 a kilogram of uranium, which is——

Mr. BARTLETT. Which is how many years' supply?

Mr. BUNN. Let us see. That would be a couple of century's worth——

Mr. BARTLETT. Okay.

Mr. BUNN.—at current rates, but, of course, if you expect nuclear energy to grow in the future, which I think many people in this room hope that it will, then, of course, you know, that—the amount of material used every year would grow. But the—that is what is sort of reported so far. And the reality is, as I said, there is a lot more out there. And particularly as you develop improved mining technology in the future, the record on, essentially, every mineral that is mined, if you look, over the past century or so, the price in real terms of extraction, rather than increasing as the good stuff gets mined out, has been decreasing because the technology has been developing faster than the good stuff gets mined out. And I would expect that to occur for uranium in the future as well.

Mr. BARTLETT. Let me ask you each very quickly to tell me how your testimony might have been different if you knew oil was going to be $100 a barrel next year.

Mr. JOHNSON. I can guarantee you my testimony would not change.

Mr. BUNN. I can guarantee you exactly the same, because as I say, I believe in the future of nuclear energy, and I believe the future of nuclear energy is best assured by not making a near-term decision to reprocess.

Dr. HAGENGRUBER. And my testimony would have been unaltered as well.

Dr. FINCK. My testimony would even be more optimistic. We need more nuclear power, certainly. But we also need ways to use nuclear power to fuel our cars. We don't have these ways today.

Mr. BARTLETT. Well, I hope there is a lot of additional uranium remaining in the world, because I suspect, as we run down Hubbard's Peak, we are going to need it.

Thank you very much, Madame Chairman.

Chairwoman BIGGERT. Thank you.

The gentleman from South Carolina, Mr. Inglis, is recognized for five minutes.

Mr. INGLIS. Thank you, Madame Chairman.

In South Carolina, you know, we have some sites that have done some work on reprocessing spent fuel from weapons used at Savannah River Site, and also some at Barnwell, South Carolina. If we went to a reprocessing approach, how attractive would those sites be as places to do that work? Mr. Johnson, particularly you. Could you comment on that?

Mr. JOHNSON. Yes, sir. Thank you.

The sites that you noted would be, I would expect, part of the evaluation that the Department would conduct as part of any national environmental policy act review that we would be required to undertake before moving forward with any kind of large scale demonstration. So I would say pretty confidently that those sites would be among the list of sites that would be evaluated for such a future use.

Mr. INGLIS. Let us see—other countries, and I have been at a markup, so I am not sure whether this has already been addressed, but other countries, Japan, France, England, Germany have all pursued reprocessing. And Mr. Johnson, do you have any comments about the success of their programs and what we can learn from those?

Mr. JOHNSON. Yes. I believe that in those countries where reprocessing technologies have been used in support of their domestic commercial nuclear power plant operation, they have been successful, with success being defined as the ability to safely and securely separate spent fuel into its constituent parts, refabricate fuel for use for power production. And in that case, I would say yes, the programs have been very successful. And there is no reason to think that the same type of success could not be seen elsewhere as well.

Mr. INGLIS. Mr. Bunn, do you agree with that or——

Mr. BUNN. I don't. If you define it in purely technical terms, they eventually manage to become successful, although in both France and Britain and particularly in Japan now they had tremendous difficulties with cost and startup problems and so on at these reprocessing plants. But if you look at the official government studies in both France and Japan, they conclude that their nuclear energy is noticeably more expensive—because they have pursued reprocessing—than it would have been had they not done so. And that is not me saying that. That is the official government studies in both of those countries saying that. And so it is hard for me to characterize that as a success when an alternative technology of dry cask storage would have provided nuclear energy with a way to manage its fuel more cheaply, more safely, and more securely.

Mr. INGLIS. Dr. Finck, do you agree or disagree with that?

Dr. FINCK. Well, I absolutely disagree, if I may. And I used to be French years ago, and I would characterize—it is not the case anymore, but I still have a little bit of pride left.

First of all, I think the French program, in my mind, has been incredibly successful. They did meet their objective. They know how to deal with their waste. And it is true their reports say there were small costs associated with closing—that cost is very small. And in view of the benefit they are getting out of it, they have accepted that small cost. I mean, nothing is free in life. Where I live, we recycle our household things, and I pay a cost to the city to recycle, so I think it is well worth it in view of the benefits of not having to bury it in my own backyard. So I—you know, as a society, we have to take into account not only the small cost increase but the whole benefits. I think the French programs, I view those as having been extremely successful. And the demonstration of success is that they have not decided to stop. If it weren't worth it, they would not go on. They are doing it. And they will continue, I believe.

Mr. INGLIS. Germany, however, has suspended their program, right?

Dr. FINCK. Germany has suspended. Basically, they are going to—they want to suspend their whole nuclear program. They want to shut down all of their nuclear plants; therefore they don't want to do anything, no nuclear energy, no reprocessing, et cetera. This is a——

Mr. BUNN. But they decided to stop reprocessing before they decided to shut down——

Dr. FINCK. Yes, let me finish. This is a political decision. My only question will be in 2015 and 2020, where will they get their electricity? They might have a real problem. They might import it across the French boundary using reactors and using reprocessing. They just happen to be down on the other side of the Rhine River, which two—the bottom line would be the same effect.

Mr. INGLIS. My time has expired.

Thank you, Madame Chairman.

Chairwoman BIGGERT. Thank you.

The gentleman from Indiana, Mr. Sodrel.

Mr. SODREL. I don't have any questions at this time. Thank you. We don't have any nuclear power plants in Indiana. We do have a lot of coal.

Chairwoman BIGGERT. The gentleman from Michigan, Mr. Schwarz.

Mr. SCHWARZ. I want to make sure that I am getting this correct, and Mr. Bunn, I guess you would be the one that I would like to have answer this, so anyone else jump in, if you feel like it.

You feel that the—we should not proceed to build any sort of reprocessing facility in this country now, that we should continue the open fuel cycle, storing the waste product, and that when we do, hopefully soon, start building new nuclear power plants, that is the technology that would be—that should be used, and if we go to the reprocessing and recycling, that would put off, significantly into the future, any expansion of the number of nuclear power plants we have in the United States. Do I have that right?

Mr. BUNN. Except for the last bit. I think my argument is not that it would inevitably put off construction of new power plants, but that it would make—because of the increased complexity of cost, safety issues, and so on, it would make public acceptance and utility acceptance of new power plants somewhat more problematic to achieve.

Mr. SCHWARZ. You led right into my next observation and question.

What is the position of the investor-owned regulated utilities in this country who potentially would build these new plants? What is their position on the issue of the open fuel cycle versus using reprocessed and recycled fuel?

Mr. BUNN. You would not be able to find a utility in the country who—that is willing to pay the cost of reprocessing its spent nuclear fuel or who would be interested in investing in a reprocessing plant today.

Mr. SCHWARZ. So for anyone on the panel, then, if we are going to—if there is a need to build new nuclear power plants, and I believe there is, the sooner the better, in my opinion, why would we be considering building any sort of a reprocessing recycling facilities or be pushing that technology now when it is not a technology we are going to use?

Dr. HAGENGRUBER. Let me just venture a comment here.

I—the industry—I can't speak for the industry, and I don't think any of us here can speak for the industry itself. But what I have heard from the industry would lead me to believe that the number one priority that they have, as far as nuclear energy is concerned, is to get a new reactor licensed and get something under construction in this country, a plan for one or several reactors. I think part of the industry that builds reactors would like to also sell a reactor to China and have some influence on that process.

I think the number two thing is they would like to get something done on the waste, that they don't want to watch another licensing period go on without some hope. So whether it is interim storage of waste or dry cask storage at an interim site or Yucca Mountain, and there, one of the issues they would like to see is something, you know, that would lead them to believe that this 100,000-year standard, which is, you know, the—gotten into the way of Yucca

Mountain, somehow that will be dealt with. I think in the case of the reprocessing, it is so far off in the future that from an economic horizon point of view, as businesses, they have to look at the issues of the reliability of the Federal Government to have a regulatory environment that allows them to predict cost so that they can transition over interest rates. And I think the last thing is not reprocessed fuel. I mean, I think technically they are interested in all of these questions, but I think it is really beyond the scope of them as a business, but we are, in fact, going to use some fuel from the nuclear weapons program, and I think they would like to actually see that successfully done and like to see a process that would actually burn these fuels, because before you start believing that these are going to have a major influence on the business you are in, you would like to really believe that there will be a business that will be predictable from a cost point of view. And so when I talk with the industry people, they are always very courteous about Generation IV and reprocessing. But it is really not on the horizon of the time that they are going to be in charge of the business.

Mr. SCHWARZ. Thank you, sir.

I yield back, Madame Chairman.

Chairwoman BIGGERT. Thank you.

I might note that we will be having a hearing later on focusing on the utilities and having them here.

And also, the utilities do pay a fee to the Nuclear Trust Fund, and that is what provides for the waste, and that is why the Federal Government takes over at that point.

I would like to recognize the gentlelady from Texas, Ms. Jackson Lee, for five minutes.

Ms. JACKSON LEE. Thank you very much, Madame Chairperson, and to the Ranking Member.

I can't imagine, even in the calmness and quietness of this room, that there could not be a more important hearing to talk about reconfiguring how we deal with nuclear waste, particularly when we mention a favorite President of mine, Jimmy Carter, but that you can describe his legacy as decades ago. And certainly, nuclear waste is not something that should be described in the concept of decades ago.

And so I would—I just would like to focus on the vitality of the question of reprocessing spent fuel. When I say the vitality, the good things that can happen by doing that. And then I would like to also—and I would like each of the witnesses to comment on that, since our friends in Japan and France have seemingly already done that. Those of us in Texas are still mourning the loss of a superconductivity lab, which is a parallel, not necessarily in sync with this, but new technology.

At the same time, I would like to wear the hat of the many concerned persons about the danger of nuclear waste, and of course, as was noted in some of the information, the concern about PUREX, but also the concern about the potential of weapons. And some of my colleagues may have asked this question. I was interestingly just in a meeting on homeland security, and so I apologize for not hearing the totality of your testimony. But I would like to hear a balanced response of the answer back on the potential threat of the creation of terrorist weapons, but the vitality of doing this processing of finding a creative way to advise the Administration, meaning Congress to advise the Administration, or set policies and standards on how we do this.

Let me also say that this question is in the backdrop of a great deal of concern and opposition that comes from both sides of the aisle with any traveling of nuclear waste, and certainly the concern that Nevadians have expressed, or persons from Nevada, in their utilization right now as to the storage place of nuclear waste.

So my first question, the vitality of reprocessing this nuclear waste, the way that we can answer the question regarding the ability of terrorists accumulating or using this for weapons, and then guidance that might be helpful now decades later in a policy that would be effective in providing a way to transport and also to, if you will, handle nuclear waste.

I could start with Mr. Johnson.

Mr. JOHNSON. Thank you.

Before I start, let me just reiterate that the Administration stands firmly behind Yucca Mountain and the need to proceed as expeditiously as possible with the completion and the opening of that facility, and that the talk that we are—the work that we are engaged in at the Department and the investigation of recycle reprocessing technologies is looked at as complementary to that activity.

Ms. JACKSON LEE. And may I just, for a moment, so I can make the record, there are many of us that don't stand behind that, but we are certainly interested in the complementary part being more than a complementary part and maybe being a fixed part. But let me hear your answer to the complementary part. Some of us are in disagreement with the Administration's position on Yucca Mountain. But you may proceed.

Mr. JOHNSON. Thank you.

Yes, well, we are very much committed to continuing to investigate the possibilities that exist in treating spent fuel, not necessarily as a pure waste, but looking at what kind of energy content—the energy content that it has, how can we recapture that, how can we minimize the waste burden on future generations through the need—or through the positive impacts in geologic disposal.

With respect to the commercial viability of the technologies, we are not there yet. We are continuing to work within the laboratories. Things look very promising at the laboratory, on the laboratory scale. There are technologies, as you know, being deployed and being in use worldwide. We think we can improve upon those, that the investigations we have going on within the Department are, we believe, vastly improved technologies over what are being used commercially worldwide.

With respect to the—your question on security, as you know, spent nuclear fuel is being stored at, roughly, 60 nuclear sites around the country. So there is a need to look at the issue of where does the spent nuclear fuel reside, for how long does it reside, and can there be some increased safety assurances by consolidation to less than the number of sites that are currently being used.

Ms. JACKSON LEE. Yes. Can I get questions—answers from the panelists? Thank you.

Mr. BUNN. I would argue that the reprocessing industry today is not a very vital one, to use your words. British Nuclear Fuels, which operates one of the world's largest commercial reprocessing plants, has announced that they are going to be out of the business in less than a decade, because they simply don't have customers anymore. France is running out of foreign customers, will continue its domestic reprocessing, but will end up using significantly less than the total reprocessing capacity that it has. Japan is about to open its new reprocessing plant after a prolonged struggle in which the utilities sort of tried without saying so publicly to get out of having to pay for it and have now—are now talking to the government about imposing a huge lines charge on all users of electricity in order to pay the immense costs of reprocessing. No other country is seriously thinking about getting into the business. I should mention that Russia is struggling to keep its last commercial reprocessing plant open, because it has so little business, and the costs are so high.

So this is, in a sense, a dying industry that we are thinking of joining here.

With respect to the terrorist risks, as I mentioned in my testimony, there has not yet been a good, credible study, a life cycle comparison of the terrorist risks of the once-through fuel cycle versus reprocessing and recycling. But if you just look at the situation, it is—the National Academy of Sciences, and others, have concluded that the risk of terrorist attack on a thick dry cask is very modest. The risk of a terrorist attack on fuel in a pool is somewhat more, particularly if the fuel is fresh enough that there is potential for a fire if the water is drained. But when you are processing the—you know, in this kind of intensely radioactive material, in huge facilities with volatile chemicals, often at high temperatures, there are more potentials for accident or for dispersing that radioactive material than there are if it is just sitting in a thick steel or concrete cask. And similarly, then you are going to be—for the transportation part, you are going to be shipping some pretty radioactive stuff from place to place in order to send it to the transmutation reactors, and that will require significant investments in security.

More broadly, with respect to actual nuclear weapons terrorism, I hope that we will not proceed with any technology that won't be reasonably resistant against theft of nuclear material for that purpose, although I have some doubts about some of the technologies we are looking at now. But the traditional approach to reprocessing involves a huge number of shipments of directly weapons-usable plutonium from place to place every year. And those—you know, the part of the nuclear materials life cycle, when it is most vulnerable to sort of overt, forcible theft, is when it is being shipped from place to place.

As I mentioned in my testimony, there is a problem worldwide with security and accounting for nuclear stockpiles, both nuclear warheads and nuclear material that could be used to make a nuclear bomb. Regardless of what we do about reprocessing, our government needs to step up its efforts very substantially to make sure that every kilogram of plutonium, every kilogram of highly-enriched uranium, every nuclear warhead worldwide, wherever it may be, is secure and accounted for, because our homeland security starts there. It starts wherever there is a vulnerable cache of nuclear material anywhere in the world that terrorists might use for a nuclear attack.

Chairwoman BIGGERT. The gentlelady's time has expired. If the next two witnesses could give very short answers, please.

Ms. JACKSON LEE. I thank the Chairwoman.

Dr. HAGENGRUBER. I will only address one part of it. I spent my whole career on issues relating to security, nuclear security. I have done many security studies, including 9/11 studies for the Department of Energy, their facilities. So let me address this in particular.

The worst places in the fuel cycle are the reactor, as the National Academy Report on Terrorism said, would be something happening at the reactor, because there is a lot of energy stored there. It can be dealt with.

The other place is when fissile material, that is plutonium or highly-enriched uranium, which is weapon-like materials, appear. Plutonium is particularly bad, because when you scatter it about, it costs an enormous amount of money to clean it up. I would disagree with my colleague, Matt Bunn, on the business about weapon-useable, because many of these things, unless they are really fuel grade, the plutonium's biggest risk is this dispersal risk. It is not easy to make a weapon out of it. Even in fuel grade, weapons—it is just very hard to make that. So just—my view of this is the reprocessing opens a door up for plutonium to be available in transport.

And here I would agree with them that, in fact, opens this risk up. And so it needs to be done with the greatest of care in terms of looking at—over at that overall system or there will be another panel like this meeting on that issue.

Thank you.

Dr. FINCK. I will try to answer very quickly.

As far as terrorist use, I think there are many options today for increasing proliferation resistance. We have heard them. The bottom line, to me, is to never separate pure weapons-useable material, and we can do that. Therefore, we never have to ship it, and it won't be very attractive to potential terrorists.

As far as vitality, Shane Johnson made a very good point. Yucca Mountain is needed whatever we do. And what we are trying to do is making better use of the one Yucca Mountain we might have soon. So we raise a real complementary effort between repository work and transmutation work.

Finally, for the question of vitality in Europe Mr. Bunn addressed, I think the issue is not deciding to go out of reprocessing. Several countries have decided to go out of nuclear in Europe, therefore, they are not doing reprocessing anymore. When the time comes, and I think it is now, where energy costs are going up and the gentleman asked the question of the cost of oil at $100, when that time comes, nuclear, I believe, will be reborn in Europe and many other countries, and the fuel cycle will have to follow, because they will need as much as I know. They will try to avoid having to build many repositories in the countries that are very dense.

Ms. JACKSON LEE. Thank you.

Chairwoman BIGGERT. Thank you.

The gentleman from Alabama, Mr. Bonner, is recognized.

Mr. BONNER. Thank you, Madame Chair, and this is a very timely conversation, I agree.

Mr. Bunn, you say in your testimony that there is little doubt that Yucca Mountain could hold far more than the current legislative limit, perhaps even all of the waste produced over the life of the existing nuclear fleet. Why are you so confident of Yucca Mountain's ability to hold more waste? And would this require an expansion of the repository? And if so, would you be willing to venture a guess of what it costs?

Mr. BUNN. Well, the costs of the repository are not—it is only a very minor portion of those costs that are related to digging more tunnels. And I am confident in part because my colleagues, Mr. Johnson and Dr. Finck, have both published reports that indicate that their view of the technical limit is 120,000 tons of heavy metal, as opposed to 70,000, which is the legislative limit. But I—the reality is that the Department hasn't really looked at the subject in the—of how you could go about expanding that capacity in any significant detail. For example, there are—you can go outward in some directions until you get to the edges of the areas that have sufficient geologic stability to deal with that situation. You can think about whether it is possible to have a second or a third tier, because currently it is just one tier, a flat repository. I have talked to a number of analysts within the Yucca Mountain program who think it is quite plausible that you could do a second or a third tier. So there are a variety of things that, as I said in my testimony, need to be looked at in more detail. The American Physical Society Panel that Dr. Hagengruber chaired also talked about the potential that it could hold all of the fuel from the existing nuclear fleet.

I should also mention, with respect to other countries, the United States is, I believe, the only country that has made the mistake of locating its repository in a mountain with fixed sides. In most other countries, they are looking at giant blocks of granite that you could put centuries of spent fuel into simply by extending the size of the tunnel. So it is, in most countries, not an issue of having to build, you know, lots and lots and lots of Yucca Mountains all of the time.

I should also mention, in respect to Dr. Hagengruber's disagreement with me, it is not just my view. It is the published view of the U.S. Government in a report sited in my prepared testimony. It is also—was gone through in some considerable detail in a report of the National Academy of Sciences that included the former Director of Lawrence Livermore Laboratory, a former Chairman of the Joint Chiefs of Staff, and so on, among its panelists. So Roger and I can talk about that more off-line after the hearing.

Mr. BONNER. If I could just ask the panel, anyone willing to take a stab at this, hearing the questioning from the gentlelady from Texas. In respect that there are many people who have different views on Yucca Mountain, but as a Nation, we are in an energy crisis, and we are depleting fossil fuels faster than we are replenishing them, and we are more and more dependent on foreign countries for energy. That would have to be a problem that we could all agree to, and yet I sit back sometimes, when I hear my friends who do not want to proceed with Yucca Mountain and yet want the benefits of nuclear power, and wonder, "What are the other alternatives out there if we don't proceed, as Chairman Hobson said before he left, with the plan that we have in front of us?" Are there other reasonable plans out there that can allow us to continue down the path of pursuing nuclear but being responsible with what we do with its waste?

Mr. BUNN. To me?

Mr. BONNER. To any of the four of you.

Mr. BUNN. Ultimately, we are going to need a nuclear waste repository. We are going to need that whether we go direct disposal or whether we pursue reprocessing and transmutation. That is clear. There isn't—unfortunately for Ms. Jackson Lee, there isn't an alternative to a nuclear waste repository. There—one could potentially cancel the Yucca Mountain and try to find a different nuclear waste repository. My own view is that that would—the prospects of political success in licensing a different nuclear waste repository somewhere in the United States before I retire are probably pretty modest.

Mr. BONNER. Anyone else disagree?

Dr. FINCK. I would like to answer that.

With the technology we have discussed today, we have a path towards sustainability on energy security in the United States by—we will need the repository, certainly, but we will need a unique repository where we will use it much better than we plan to use it today. It will last us well beyond this century. So there are ways to make nuclear much more sustainable than what we are doing today.

Dr. HAGENGRUBER. I would like to just offer a comment on that.

I—that was the first study I did back in 1972. And at the time, we were classifying separated waste from reprocessing at Hanford. We were also doing work at Savannah River Site. And there was waste being stored in tanks in Idaho. It was very obvious, at the time, that engineered storage, which is storage that might be monitored—retrievable storage that might be monitored for hundreds of years into the future as a concept with something that was not hard to do, that trying to get a solution that would meet people's acceptable standard of permanent disposal with no chance of anything ever being returned to the environment was too hard. It is just as hard, in fact, it is even worse now, because the legal barriers to making any kind of progress are higher. The prospect—you know, I don't know how you will deal with the 100,000-year standard. It is too ice age for—and we don't know of any technology that is going to survive that. So practically speaking, I think a permanent disposal repository for nuclear waste is something that probably 30 years from now, somebody will be sitting here talking about the same thing, because it still hasn't happened. I think that what people will have to face is that we have very poor interim intermediate storage capabilities by using reactors as places to store stuff. We need to get on with the business of accepting the fact that it is not 100,000 years later some guy with a burrow digging a hole in the ground is going to be the measure whether we did a good job on permanent storage. But the fight over Yucca Mountain is a fight that existed, by the way, very strongly in the 1970s, but for different things. It wasn't Yucca Mountain then. It was deep-sea beds and granitic disposal, glass rods. It was the same kind of arguments you see today. It is 30 years later, and we still haven't made any progress. I am not a cynic, but I guess, realistically, I have—a physicist that has become an engineer. I would just get on with the job of some regional intermediate storage with dry cask storage and just expect to take care of it for the rest of our existence.

Mr. BONNER. Thank you, Madame Chair.

Chairwoman BIGGERT. Thank you.

The gentleman from Missouri, Mr. Akin, is recognized.

Mr. AKIN. Thank you, Madame Chair.

I had a bunch of questions, and I hope a couple of them maybe have fairly short answers.

The first one was, somewhere or other I had heard that if you were just volumetrically to take the spent nuclear fuel that we have so far and stack it on a football field, it would end up about a meter or so deep. I understand that, from a thermal point of view, that wouldn't work very well, but just volumetrically, if you stacked it on a football field, is that about right? About a meter?

Mr. BUNN. I haven't done that calculation, but it sounds like the right order of magnitude.

Mr. AKIN. Reasonable? Okay.

The second question——

Mr. BUNN. It is not huge volumes of stuff, you know, but——

Mr. AKIN. It generates a lot of heat, that is the——

Mr. BUNN. The total amount is less than, you know, the waste from a coal power plant—one coal power plant every year.

Mr. AKIN. Okay. The second question is the small, inexpensive reactors possibly with—what generation would they be? Third generation or fourth or what?

Mr. BUNN. Probably fourth.

Mr. AKIN. Fourth generation? First of all, my question is, are they available now, if we said, all of a sudden, we are so sick of paying for this oil. We are just going to build them, how long would it take us to get to the point where we would actually start digging some dirt and pouring some concrete and all?

Mr. JOHNSON. If you are referring to some of the small, Generation IV reactor technologies that we have just begun, essentially, conceptualizing, we are, you know, a decade or more away from seeing any kind of commercialization of that particular technology, although I would——

Mr. AKIN. So those are the things that people talk about that it is pelletized, kind of, in ceramic pellets and that they are very small——

Mr. JOHNSON. Oh, you are talking about the pebble bed? The pebble bed could be done somewhat sooner, potentially. There are smaller, as Mr. Bunn has eluded to, what is called a pebble bed, gas-cooled reactor technology that has been under development both in Japan and South Africa predominately that builds upon earlier German technologies. Those have been looked at by U.S. industry recently, although there is no one in industry currently pursuing that particular technology.

Mr. AKIN. Would that be called third generation? Maybe?

Mr. BUNN. Probably.

Mr. JOHNSON. Probably.

Mr. AKIN. Okay. So you are saying we are 10 years away, at a minimum, from a small, fourth generation type of facility?

Mr. JOHNSON. At least, yes.

Mr. AKIN. At least. Okay. If you had to build something now, what would you build?

Mr. JOHNSON. Well, as you may know, the commercial industry in this country is looking at the next generation light water reactor technologies, which build off the technology base that is currently deployed at 103 sites—or 103 reactors across our country. So they are looking at, essentially, an evolution of the current technology that is——

Mr. AKIN. A further improvement of what we have already had?

Mr. JOHNSON. Yes, sir.

Mr. AKIN. Okay. Is that the same thing the Navy uses in their different ships and all? The same general technology?

Mr. JOHNSON. The base technology of a pressurized reactor, or a boiling water reactor, yes. But there are considerable differences in fuel and the operation of those facilities.

Mr. AKIN. Just because the nature of what they are trying to accomplish is a lot different?

Mr. JOHNSON. Correct.

Mr. AKIN. Okay. And now is it true that what you said that depending on how you come out on reprocessing might change the design somewhat of the power plant?

Mr. JOHNSON. Yes, what I was trying to address was the Chairlady's question on the integration of our Generation IV reactor program and our fuels development program that those are integrated. They are interrelated. And it is an integrative process of trying to optimize the fuel to meet both power production requirements, waste minimization, and also enhances proliferation resistance to——

Mr. AKIN. So dry cask storage, that—would you take that off of the table, if you were talking about reprocessing then it may change your design parameter somewhat? Because if you are dry cask storage, you could use whatever gives you the most power out of the material and then you get rid of what is left over, right?

Mr. JOHNSON. Yes, but I don't want to say that you would not have, somewhere in the process, the need for dry cask storage at some point in the process.

Mr. AKIN. Okay. The third thing was—and this was a point, I think, that you were making, Mr. Bunn, pretty heavily, and that is this reprocessing cost can drive the thing out of economic range. Relative to relative cost, and that was where, I gather, you disagreed with Mr. Finck. You are saying it is a relatively small cost and a responsible cost to add. Mr. Bunn, you are saying it is just disproportionately so large it makes it impractical. Better to postpone the problem until the technology develops a little bit more. We can always come back and catch it later at a lower cost. What is the relative cost of the reprocessing in the overall process? Are we talking about adding five percent or doubling the cost of electricity, or what would be the effect on the cost of electricity to the consumer if——

Mr. BUNN. The effect on the cost of electricity, actually Dr. Finck and I don't disagree, is relatively modest, because the advantage of nuclear power, when you look at—when you compare it to other electricity sources, is that its whole fuel cost is pretty modest, because the energy in its fuel is so concentrated. So the main cost in nuclear energy is the capital cost of the nuclear plant that you have built. And so the total contribution to electricity generation costs would be relatively modest, a few percent, probably, depending on how expensive the reprocessing and the recycling ended up being.

But that is a little bit like saying, "Well, I should be willing to pay $300 rather than $100 for a pair of shoes, because it is still a small proportion of the cost of my wardrobe." And the reality is, if you look at the cost of nuclear waste management, which is one of the few costs that the owner of a nuclear power plant that is already built can still control going forward, you are, of order, doubling that cost of nuclear waste management, if you are going forward with reprocessing and recycling, as traditionally practiced, using the cost—you know, if we had a plant that was government-financed at low cost, and if it had the same—managed to achieve the same capital and operating costs as the most efficient plants that exist today in France and Britain. So you know, a utility is not going to want to do that. So they—if left to the private market, reprocessing wouldn't happen. So then, as I said, you have to do one of three things. You either have to substantially increase the nuclear waste fee, which utilities are going to scream bloody murder about, or you are going to have to have the government provide tens of billions of dollars in subsidies over decades, and you know, while it is a small contribution to electricity, tens of billions of dollars is significant money. If we were talking about a weapons system, we would agree that that was an expensive weapons system. Or third, you are going to have to impose regulations that force the industry to take it out of their own bottom line and build these facilities themselves.

Mr. AKIN. And let me just stop you for a minute. Somehow or another there was a little leap here of reasoning that I didn't catch. Okay. What I was asking was, let us say—first of all, let us start with the assumption that the government is not going to subsidize anything. We are just going to try to keep the lawyers at bay and the politics at bay and let us just deal with it just from an engineering—let us—a perfect world.

Mr. BUNN. Right.

Mr. AKIN. My question is, the total cost for generating, obviously you have got to put the plant cost in and your cost of capital to build it all. And so I am saying that is built into the cost to the consumable electricity.

Mr. BUNN. Right.

Mr. AKIN. What you are saying is the reprocessing is still a small portion of——

Mr. BUNN. It is a small portion of that——

Mr. AKIN.—the overall——

Mr. BUNN.—total cost.

Mr. AKIN.—electrical establishment?

Mr. BUNN. Correct.

Mr. AKIN. Okay.

Mr. BUNN. Correct. That is what I am saying. And what—all I was saying, with respect to the regulations or the fee was how do we make that money for that small additional cost appear. You have got to either charge the utilities for it or force them to pay for it themselves or the government has to pay for it itself. Those are the only three options I can think of anyway.

Chairwoman BIGGERT. The gentleman's time has expired. We will have a second round of questioning.

Mr. AKIN. Thank you.

Chairwoman BIGGERT. We are experiencing technical difficulties. We will also be having a hearing on cost later on.

So the gentleman from Michigan, the physicist, Dr. Ehlers.

Mr. EHLERS. That puts a heavy burden on me.

I—it is interesting listening to this, because the first in-depth look I took of this was in the late 1970s, slightly after you did, Dr. Hagengruber. And it doesn't seem much has changed. But I look at—I took a good look at this, because I was teaching a course on the environment, and I was also a member of the Sierra Club, which was adamantly opposed to nuclear power. And so I looked very carefully at the various forms of generating electricity and came to the conclusion that nuclear power and fossil-generated power are about equally bad. And I ended up disagreeing with the Sierra Club, which I was a member then and still am, in spite of occasional difficulties with them. I came down on the side of nuclear power, because the base—the biggest problems that you had to deal with, with the fossil-fueled plants, is the greenhouse gas effect. The biggest problem of the nuclear plants is the disposal of the radioactive waste. In other words, in both cases, dealing with the waste products. And I felt much, much more comfortable dealing with a compact, solid material that is a waste product than a gaseous dispersed product, which is virtually impossible to deal with capture, and we talk about a lot of solutions, but none of them look as easy as either reprocessing or storage of waste.

I would also pick up on Dr. Hagengruber's comment on the—I am supposed to be at another meeting, so I am sure I am being summoned.

Dr. Hagengruber's comment was about disposal versus storage. And he is absolutely right. I got into politics because of an environmental problem in my area. That was ordinary, solid waste. And one of the things I proposed is that we change the name of our landfill from the Kent County Solid Waste Disposal Facility to the Kent County Solid Waste Storage Facility, because it is still there. And it is still there and it is still creating problems. And we have to recognize that. Yucca Mountain, I think the legislative language that we put on Yucca Mountain is just impossible to fulfill, and we ought to wake up to that, and I have tried to wake my colleagues up to that. Monitored, retrievable storage is the only viable solution politically, because you can not guarantee that this will—that if you just stick it in the ground and leave it there it is never going to leak, never going to create problems.

I always thought that recycling of waste was a good idea. And Mr. Bunn, you seem to argue against it on, primarily, economic grounds. I would point out, if there is that much excess capacity in other parts of the world, I would be perfectly happy to ship it over there and let them reprocess it and pay for it.

The—I also would disagree, and this is because I have to leave for another meeting. I am not—I am just stating my opinions here and will not—probably not have time to listen to your responses, but the economic argument, I don't think, is a valid one in this case. I find it hard to believe that the cost of recycling the waste is going to be greater than the perpetual care over the long-term of the stored waste, because I think the only way to do it is to set up a trust fund to make sure the money is always there, otherwise there are going to be political hassles every year about the cost of that.

I would also point out that this is not a cost on the utilities. It is a cost on the customers. We have been talking about the utilities pay this fee that they are paying now. That goes right into the rate base, and since they are mostly regulated industries, it is the customers who really pay the bill. And so I feel comfortable just—if, in fact, recycling is a better alternative, I feel comfortable just telling the customers that that is a fee that has to be paid as part of the total cost of the system.

So I haven't quite exhausted my time. There are probably 30 seconds, if any of you would like to respond and argue with me or say something different about it.

Mr. BUNN. Well, I would like to argue with you a bit. I think that you and I are supporting the same option, which is monitored retrievable storage. I believe that if we put the fuel in storage while moving forward in a responsible way with a geologic repository, that we are going to leave open whatever option we take. Then we can allow time for technology to develop. We can allow time for interest to accumulate on funds that we set aside today. And I completely agree that the only way to manage a geologic waste repository, which we are going to need, again, no matter what path we take, is to set aside a trust fund so that the money will always be available. But with the wonders of compound interest, that is possible to do without spending enormous amounts of money today.

So I think that that is really the best path forward: to continue looking at the technology, but not to make a rush to judgment today on technologies that currently are more expensive, more risky, and more proliferation-prone than the alternatives.

Mr. EHLERS. Okay. And I don't have that much argument with that. Obviously, we have to know what we are going to do. But I—the difficulty of siting, I think, is the biggest problem with the storage system. And I think it is a large enough problem that recycling will have to—just so that you don't have to cite as many sites. And the economics may not win in this case. The politics may win.

Mr. BUNN. But then you have to site the reprocessing and transmutation facilities, and since they will pose greater hazards to their neighbors than a repository will, that may be even more difficult.

Mr. EHLERS. Well, possibly, but I am not convinced that it would pose greater hazards, if it is done properly. And after all, we have two polluted sites we can start with and just build a large perimeter fence around them and say, "Okay. Keep on doing it." But I don't—I think your view of the dangers is somewhat exaggerated.

Madame Chairwoman, I appreciate your consideration, and I yield back the balance of my time.

Chairwoman BIGGERT. Thank you very much, Mr. Ehlers.

And we will start a second round now. And Mr. Honda, why don't you——

Mr. HONDA. Madame Chairwoman, let me yield to Mr. Matheson, please.

Mr. MATHESON. Well, thank you, Mr. Honda.

The question I would like to ask about is in the evaluation of reprocessing, I am assuming that there would—if we moved ahead with the commercial effort of reprocessing at some point, we would have it at a few sites around the country, or perhaps fewer than a few?

Mr. BUNN. Maybe only one. Who knows?

Mr. MATHESON. In terms of looking at all of this effort for R&D and reprocessing, what effort is being looked at in assessing the risk of transporting of the waste to another site?

Mr. BUNN. Do you want to handle that?

Mr. JOHNSON. Well, with respect to our Advanced Fuel Cycle Initiative, we are not looking at transportation issues. Probably the only part of the Department that is looking at transportation issues associated with spent nuclear fuel would be the Office of Civilian Radioactive Waste Management, and to their work, I apologize, but I can't really address.

Mr. BUNN. There is a fairly substantial R&D effort in the Department related—not—I wouldn't say—R&D is the wrong word. A fairly substantial effort to look into what measure should be applied to secured transports of spent fuel, and there is a—what is called the Transportation Safeguards Division within DOE that today safeguards shipments such as how weapons are shipped from place to place.

Mr. MATHESON. It may be getting a little outside of the scope of this hearing, but as a member of the Transportation Committee, we held a hearing in Las Vegas talking about transportation relative to moving waste to Yucca Mountain. I was not given a lot of assurance that the Department has really done a lot of work on assessing transportation risk of nuclear waste, and so it would be an interesting issue to——

Mr. BUNN. I don't disagree with the—your assessment of the adequacy of what has been done so far.

Mr. MATHESON. Well, since I am from a state where 95 percent of that waste would go through, I have a certain interest in this issue.

Dr. HAGENGRUBER. Let me just speak, because on that—I think people have said the right thing. The RW Office actually is the one that is taking the responsibility for the security aspects of transportation. There has been work done. I know, because some of the work was done at—you know, involving Sandia National Labs. Some of the work in the transportation area, including the transportation of casks, for instance, fuel casks and accidents that occur, the idea of people shooting weapons at fuel casks or transport casks, that work goes back 25 or 30 years. So there is—if you look at the integrated total of the amount of money that has gone into both purposeful and accidental attacks on the transportation of fresh fuel and spent fuel, there has been a lot of work, and we are talking about many, many millions of dollars.

Now in particular, RW has been looking at—was looking at the question of whether or not to federalize the transportation or to make it commercial in its nature. Transportation Security Division, one that Matt mentioned, transports, in effect, trigger quantities of material weapons and pits and other types of material. And it is a very, very expensive thing. The trucks cost a couple of million dollars. They have a full cadre of highly trained, armed forces with them. They have constant communication. If you were to move to that, the implications in cost and transportation of anything, whether you have a reprocessing plant, spent fuel, or doing anything, would become staggering.

The question of federalization of the forces, that is to actually have federal people driving those trucks, has additional cost implications. But I think it is wrong to believe that there hasn't been work done. I mean, you may have been talking with people that don't know the historical work that was done. You may have been talking about people that don't know what RW was trying to do. Whether it is adequate or not, in light of this, I don't know, but I know that it has gone far enough to do studies looking at all of the donor sites, of which there are—I think there are 106 or 108, not just the operating reactors. And there are certainly—there is a stack of documents this thick on security at Yucca Mountain, including the transportation from the entry to Yucca Mountain to the location at the Yucca Mountain site. I know this, because I—the National Academy panel that I am part of was asked to consider doing a study on research and development and the security at Yucca Mountain. So we have seen some of those reports. I don't think—it may not be enough, sir, but there is a substantial amount of work out there.

Mr. MATHESON. Thank you, Madame Chair.

Chairwoman BIGGERT. Thank you.

Do you have any more questions, Mr. Honda?

Mr. HONDA. Just a quick question, and this is probably reflective of my ignorance. But what I have heard is that, and I think it was Mr. Johnson that indicated that the reprocessing of uranium is, what, 96 percent or 94 percent of its total weight in volume, I guess. And encapsulating that for storage, that is one step, but aren't there other byproducts of reprocessing or of creating the waste that other materials have to be encapsulated, also, so that in practice it appears that there will be more volume than just the waste itself. There are other wastes that are created so that the volume is really more. If that is the case, then how does that really solve our storage and our nuclear waste problem?

Mr. JOHNSON. Yes. What I was referring to was that, by mass, uranium constitutes 96 percent of the mass of spent nuclear fuel, and that uranium is primarily uranium—the isotope uranium-238. The fissile content of the uranium-235 in spent nuclear fuel is slightly above that of natural uranium. It is roughly—it is a little less than 1 percent, on average. You are correct in that the separations technologies that we are currently investigating within our—the Department's programs, is looking at partitioning spent fuel into different—into its different constituents, separating out the uranium. That does provide significant volume reduction, but as I mentioned earlier, the primary concern in repository performance is the heat generation. And that heat generation is driven both in a short-term and a long-term component. By separating the spent fuel into these different elemental constituents, yes, you have not really reduced the amount of material, it—the amount of material that has to be stored, but it is the recognition that all of that material doesn't then have to go into a geologic repository. For example, the uranium can be extracted at such purity that it could possibly be stored as a low-level class C waste. It would meet that type of requirement that would therefore not need to go into a repository—into a geologic repository. The other constituents could be stored for future destruction or transmutation in future fast reactor systems that would minimize the volume of the highly radioactive materials that would have to go into a repository.

Mr. BUNN. I think that—I agree with Dr. Finck that what we need is an end-to-end systems analysis on this kind of thing, because when you look at reprocessing, you have got, depending on which technologies you are using, a variety of different streams of high-level waste or species you are going to send for transmutation, but you also then have to look at intermediate-level waste, low-level waste. You have to look at, when you are done with the reprocessing plant, when it has outlived its lifetime, the decommissioning waste, the same for the transmutation facilities and so on. And then you have to compare the costs of managing those various different waste streams and the hazards of managing those various waste streams and hazards with other options. So I think that is the kind of examination that needs to be done. The cost—the volumes of, for example, decommissioning waste projected from the reprocessing plants in France are quite large.

Dr. FINCK. If I may, volume in Yucca Mountain is not the issue, as the gentleman is saying. The issue is heat load generation, and most of the heat load comes from a few percent of the waste. That is what we have to deal with. Essentially, we have to get rid of that heat to increase the capacity of Yucca Mountain. No, I fully agree. We have to look at an integrated cycle to see where the benefits and costs are and to gain where we can.

Mr. HONDA. So the other wastes that are created that have to be contained, you are saying that those are safe and all we have to do is find a storage place for them?

Dr. FINCK. No, the ones that are toxic. What we want to do is transmute them. Basically take them, let us say, americium-241, and fission it into elements or isotopes that are much less toxic. And you do this by running it through a—in a reactor.

Mr. HONDA. And is this what is happening in France and in Japan and in the UK where they are completely being able to deal with their waste or——

Dr. FINCK. No.

Mr. HONDA.—do they have waste issues, also?

Mr. BUNN. Go ahead.

Dr. FINCK. They take the first step there. They take care of one of the elements, one of the isotopes. They take care of plutonium-239 by burning it partially, but they plan, in the future, to do exactly what we described earlier, take care of the other elements, which we usually call minor actinides. And their plans for the years to come, roughly when we plan to do it, is also to find ways to destroy these minor actinides. But right now, they only burn plutonium-239 partially, and they store the resulting fuels and the resulting minor actinides are stored for future use.

Mr. BUNN. But the way that they are implementing reprocessing today, with, as Dr. Finck said, one round of recycling of the plutonium as in plutonium mixed-oxide, or MOX, fuel, in their existing light water reactors, has essentially no noticeable waste management benefits. As Dr. Finck and Mr. Johnson have both said, the volume and cost of a repository is determined by the heat output, while if you go to a system with one round of reprocessing and MOX and then disposal, you actually have more heat rather than less for—compared to a direct disposal per unit—you know, per number of kilowatt hours generated. And you don't have any significant reduction in the radiological toxicity, the doses from the repository, because the only thing you are separating is the uranium and the plutonium, and those, basically, don't contribute significantly to the doses—from geologic repositories. So you really have to go to the kinds of transmutation technologies that Dr. Finck is developing in order to get the kinds of benefits that——

Dr. FINCK. If I may complement. We actually get a very small benefit from MOX. It is like 10 percent, not really big.

Mr. BUNN. The studies I have seen go the other direction, but we can talk about that.

Dr. FINCK. Well, I like to do my own studies.

Mr. HONDA. Well, through the Chair and—I just want to thank you for your testimony, but my sense is that it is much more complicated of an issue that requires a systems approach to look at the entire problem and look in that—some matrix that would address the issues of proliferation and the dangers intermittently——

Mr. BUNN. And for that reason——

Mr. HONDA.—combined together rather than just talking about storage and transferring to other countries for processing and coming back. It is much more complicated than that, and I appreciate the—your input in providing this insight for me.

Chairwoman BIGGERT. Thank you.

I am glad that Mr. Honda brought this back to the systems analysis, because I think that is where we needed to go back. I would like to go one step further back, and I think in my opening statement I talked about the log and how we take three percent off one side and three percent on the other end and throw the rest into the fire to burn and then we take it out and put it in a mountain, or we are going to try.

When I was—in the 1960s and I first went to France, and I can remember going to these hotels. We used to go in Europe on $5 a day. That doesn't happen anymore, but it was—we would go to these hotels, and you would walk into the hotel, and you would come in at night, and to turn on the lights to go up the stairs, you would push a little button and the lights would go on, and then you would get—try and make it to the top of that staircase to push the next button, because the next staircase the lights were going to—and having been to France since then, you know, things have changed. They—the electricity that is there, you don't drive with your—just the car headlights anymore, the buildings are lit up like it was never before. And 80 percent of France's electricity is nuclear. Ours is 20 percent. Now I live in a state that is over 50 percent electric, because we have had a lot of nuclear facilities there. My point is that, you know, here we have a clean, environmentally-friendly energy source, and we keep saying, "Well, we should wait. We should wait and, you know, just use that small amount of the energy, the fuel, and let the—just burn up the rest or—and then put it away." And that concerns me that in—you know, for future generations, we have got to find means of energy that is going to be—to have that rather than being oil now—oil dependent. Now we don't need electricity, but we need natural gas. We need different fuels that are not going to be around, fossil fuels. And I think that this is imperative that we start to work on it, because the time it is going to take to create the fast reactor where we are going to have the closed fuel cycle and be able to do all of this in one place and really, you know, time after time use this fuel until it is gone and then have this small amount to put into Yucca Mountain. And it always seems to come down to the issue of non-proliferation. That is the first—everything everybody says, and I know that this has been worked on for years and years. France is using something that is really outdated, compared to what we can do now, and just for one thing that Mr. Bunn said that—you know, you had said that there are 240 tons of separated—where—weapons-usable plutonium already exists throughout the world. So you know, I know we have to be concerned about terrorists, but—seeking nuclear material, but if there is plutonium that is being used and produced by UREX+ and even if it isn't lethal, wouldn't somebody—you know, somebody go after the pure plutonium that they can find rather than something that has, you know, been reprocessed like that?

Mr. BUNN. Well, I, for one, agree that there are a huge number of places in the world that, today at least, are sufficiently vulnerable that have either highly-enriched uranium or plutonium that they would be the places of choice for terrorists to get that kind of material. And one of the points I made in my testimony is that we, as a Nation, have to be working as fast as we can to lock down all of those stockpiles.

I don't think that proliferation is the only issue here. I agree with you that nuclear energy is something that I would like to see grow as one of the potential answers to climate change——

Chairwoman BIGGERT. And don't you think that——

Mr. BUNN.—but I don't think we need reprocessing as part of that. In fact, I think a near-term decision to reprocess would be more likely to undermine than to promote the future of nuclear energy.

Chairwoman BIGGERT. But don't you think that we really need to take in the cost consideration of the global climate?

Mr. BUNN. Absolutely. And because we need to take into the cost consideration, that is one of the reasons why I think we shouldn't reprocess. The cost of climate change is an issue of nuclear energy——

Chairwoman BIGGERT. But what we will be spending for other types of—like the carbon that is—you know, that is creating the problems, and if we have the nuclear, then that is going to change the costs that we are going to have to spend on the environment.

Mr. BUNN. But what I am saying is you can have nuclear energy without reprocessing. In fact, I believe you are more likely to have growth in nuclear energy if we don't pursue reprocessing with the technologies that are available now or in the near-term.

Chairwoman BIGGERT. But having been over in France and having seen those pools and the way that the storage is, I mean, they are getting to—you know, like the big rooms, like the football field with the cask, and then you have got the water pool in the other room. And that is—you know, they are doing well, but when we can reduce, you know, the amount of radioactivity and the heat to where—to—down to, let us say, 300 years versus 10,000 years, that is a big difference in a cost to us as far as, you know, having the ability to put that some place.

Dr. HAGENGRUBER. If I could just make a comment.

I think it is really important in the systems analysis to also look at the history of how the government participated in the industry, not only in this country, but in France, and how they participate today, just like Airbus and Boeing, are interesting issues.

I think the other thing is that from a systems point of view, this is the only energy source that we are going to look at, that attractive energy source, where the government will bear an enormous burden. It is worse than ethanol or solar energy or geothermal in terms of the subsidy, because you will not be able to create an industry that would freely build this reprocessing plant, would freely move and recycle the material, would freely build the generations of reactors in which it would most efficiently be done if the entire—almost the entire research and development burden for this, not just the reprocessing facility, the Generation IV reactors, everything, will be borne by the government, and that is quite unlike any other energy source. If you put that into the context, then, of how much we spend dealing with the threat of nuclear weapons or the threat of proliferation of weapons of mass destruction, it means that—I mean, I actually believe, from a physicist's point of view, recycling makes sense for the very reasons that you say. On the other hand, proliferation has been a persistent problem. It is an emotional problem. It is one that gets into the deepest sense of fear that people have. And it affects the political environment, the cycles of support and non-support for nuclear energy. We have seen those cycles now since the Manhattan Project, and we will see them again. It seems to me that it behooves us then to make a decision that is most robust that draws the most constituency across the political spectrum. And I think that decision should include the closed cycle. But I think the time—the timing of the closed cycle is something where there should be an exquisite attention paid not to how efficiently we could get the Department of Energy to do the research, but how much the Congress, committees like this, could demand that the standards of proliferation be reasonably answered when they see the alternative technologies, because in the end, Madame Chairman, you and your colleagues will bear almost the entire cost of the development of this part of the cycle.

Chairwoman BIGGERT. Well, I know that, you know, the Administration has come out and said we need to move forward with the advanced fuel. And there has been some discussion that, you know, the cost of doing the first fast reactor or doing the first—the whole process is going to be huge. But once that is built, then it will reduce the costs that the utilities will be able to come in and do that, is that something that you think is possible?

Dr. HAGENGRUBER. We have—we built a fast reactor in Tennessee, essentially completed. And it did not run. We built the West Valley field facility for recycling, and it ran for a few years and was shut down.

Chairwoman BIGGERT. But we actually had one in Illinois, too, that was built but never opened.

Dr. HAGENGRUBER. Right. And it seems to me that it goes back to the——

Chairwoman BIGGERT. But that was political.

Dr. HAGENGRUBER. But it is just, in a way—well, but that is my point is it is not physics. And it is—and we are not the threat of proliferation. Our material is very unlikely to be truly the threat to terrorists, even in this country, because we do provide a high level of security. It certainly is true in France. The security is exquisite. In the end, the question is whether or not the international regime we launch now, as we did in the 1950s, launched the nuclear regime that is around the world, whether or not that regime will be one we want to live with, you know, in the—for the next 20 years.

Chairwoman BIGGERT. Well, we launched that, but I would say in the 1970s, you know, we said shut down all of the reprocessing. The United States did. Nobody else did, and they haven't followed our lead on that. Do you think we are still a leader in this industry at the moment?

Dr. HAGENGRUBER. I think that the—I believe that the international community still looks to the United States in terms of, like, the permanent geologic repository, I know from my discussions with the RW people, that people in France and everywhere look to the United States asking, "What are you going to do?" They look at Yucca Mountain to see. I think in the question of reprocessing and what will happen to an economy, a plutonium economy in the world, the question about Generation IV reactors, the investments that our government makes will be the ones that set the standards. So even though there have been countries that are successfully reprocessing, et cetera, is that the reactors the French are trying to sell to China are the reactors that were developed in the technology here in the United States. It is changed somewhat, but they are not an original design. And so, you know, in the end, we will have a major influence. The decisions made, you know, in these next few years will have a major influence on what the world decides. And even though we should have lost our leadership, I mean, we have been sitting still for 25 years, we have not. I mean, there is still—they will look to us to see how much of an investment we make. Generation IV, the advanced fuel cycle, these decisions are ones in which the U.S. leadership will have a profound effect on the world's decisions.

Chairwoman BIGGERT. Dr. Finck.

Dr. FINCK. Yeah, if I may, two comments.

I would like the United States to regain leadership in the nuclear business. I wouldn't be as optimistic as Dr. Hagengruber that we have kept everything. For example, in the repository, sure they look at our solution, but as Matt Bunn was saying, we are the only one to have put it in a mountain with limited walls. They are looking at very different solutions. Maybe, possibly, they are learning from our mistakes. I don't know.

But you know, one more thing I would comment on, we need to stop thinking the same way we were thinking 30 years ago. The world has really changed. Global warming is, today, a recognized issue, at least by many scientists, and it is going to affect the future, maybe not mine, but certainly my children and grandchildren. It will affect more than any other program we had in our civilization before. We—oil, the price of oil has gone up, and I believe, unlike in the past where we have oil crisis due to a supply of political issue on the supply side, this time it has to deal with a major increase in demand, mostly in China and India. And I believe, I might be wrong, and hopefully I am wrong, the price of oil will be up for a very, very long time, maybe forever because these countries are consuming more. So the world has really changed, and the way we look at nuclear must address these changes, too. We need to increase nuclear to have a cleaner environment, to have more secure energy, and if we do not deal with the waste problem, that will prevent nuclear from moving forward. We need to deal with it.

Chairwoman BIGGERT. Thank you very much.

Mr. Bunn.

Mr. BUNN. I believe that we do have some leadership and some influence on other countries, and that is part of the reason that I am concerned that President Bush's approach, where he has made stopping the spread of reprocessing to additional countries a key element of his nonproliferation policy, will be more difficult to carry out if we, ourselves, are moving forward with large-scale commercial reprocessing in our country. If we are doing it, it will be more difficult to convince others not to. Countries like South Korea and Taiwan have both expressed interest in reprocessing. They have been not pursuing it, because of U.S. pressure, and they both had secret nuclear weapons programs based on reprocessing in the past that were stopped under U.S. pressure. We just read in the newspaper this morning about additional secret reprocessing work in Iran that the IAEA has reported. So I think a nontrivial part of the consideration is what influence will this have on our ability to convince other countries to follow what is a significant part of President Bush's nonproliferation——

Chairwoman BIGGERT. So I guess what you are saying is that we shouldn't move forward in our research and development if another country might do it, too?

Mr. BUNN. That is not correct. I have strongly supported continued research and development in my testimony. What I am saying is we should allow time for the technology to develop. We have available today commercially safe, cheap, reliable ways to manage our nuclear fuel for decades to come. We should allow the time for a responsible decision with more development of the technology.

Chairwoman BIGGERT. Mr. Johnson, do you have anything to add?

Mr. JOHNSON. No, ma'am.

Chairwoman BIGGERT. No? Okay. Thank you, all. Thank you, all of the panelists today, for testifying before this subcommittee, and I really appreciate all that you have—the expertise that you have brought to this Committee. And obviously, this is a very complex issue, and we will be holding further hearings, and I know that it is—I think we do have a responsibility to know all of the facts and make decisions based on that, and I appreciate all that you have contributed to that.

So if there is no objection, the record will remain open for additional statements from the members and for answers to any follow-up questions the Subcommittee may ask the panelists. Without objection, so ordered.

The hearing is now adjourned.

[Whereupon, at 12:34 p.m., the Subcommittee was adjourned.]

Appendix:

ANSWERS TO POST-HEARING QUESTIONS

Answers to Post-Hearing Questions

Responses by Robert Shane Johnson, Acting Director, Office of Nuclear Energy, Science, and Technology; Deputy Director for Technology, U.S. Department of Energy

Questions submitted by Chairman Judy Biggert

Q1. There was some discussion during the hearing about the economics of reprocessing, once it becomes commercial scale. What are the major steps necessary before the technology is mature enough for commercial deployment? For each of those steps, do we have enough information to estimate the associated costs? If so, what are the costs?

A1. Assuming that any near-term (e.g., within twenty years) commercial deployment in the United States would involve one of the UREX+ flow sheet variations, the major steps remaining are (1) completion of both laboratory-scale experiments and modeling efforts to characterize the selected flow sheet and its associated control/accountability system, and (2) successful testing at an engineering scale of the integrated flow sheet and controls. Some preliminary cost estimates have been made based on laboratory experience to date plus related data from commercial scale separations operations in foreign countries. Additional research and development is needed to identify the losses between process steps and the scalability of the technology.

Questions submitted by Representative Dave G. Reichert

Q1. I understand that there is likely to be a shortfall of trained professional nuclear engineers, nuclear scientists, health physicists, radiochemists and actinide specialists brought on in part by the impending retirement of a substantial portion of the national lab staff with experience in these fields. I am further advised that Universities in my state with leading radiochemistry programs are hindered in attracting nuclear science and engineering students.

- *How will a renewed development of the nuclear fuel cycle, including nuclear reprocessing, in the U.S. be staffed with competent scientists and engineers?*

A1. The Department of Energy's (DOE) Office of Nuclear Energy, Science and Technology's (NE) supports nuclear science, radiochemistry, health physics, and engineering programs at U.S. colleges and universities through the University reactor Infrastructure and Education Assistance program (University Programs). This program has been in place for over a decade and it along with the efforts of universities and industry has led to a significant increase in enrollments in these programs. For example, nuclear engineering programs in the U.S. increased from 490 students in 1998 to more than 1,500 today. Additionally, the Department provides targeted opportunities to outstanding students interested in disciplines related to nuclear fuel cycles, through fellowships awarded through the Advanced Fuel Cycle Initiative.

Q2. Numerous National Academy studies have emphasized the need for international cooperation and collaboration in the development of future nuclear fuel cycles.

- *What role might international agreements play in the growth of our involvement in closing the loop on the nuclear fuel cycle? In other words, how might we achieve a mutual benefit through cooperation with the French, the Japanese or the Russians who are all involved in advanced fuel cycle work?*

A2. The Department is actively engaged with several other countries in developing next-generation nuclear energy systems including advanced, proliferation-resistant fuels and fuel cycles. Through the Generation IV Nuclear Energy Systems Initiative, the Advanced Fuel Cycle Initiative (AFCI) and the International Nuclear Energy Research Initiative (INERI), collaborative research and development (R&D) into advanced fuel cycles, including treatment and recycling of spent nuclear fuel, has been underway for over four years. The United States is currently collaborating with France, Japan, and the European Union. The United States is gaining insight into other countries' recent operational experience and sharing in their expertise as new, improved, proliferation-resistant advanced fuel cycle technologies are jointly developed. These cooperative activities involving spent fuel reprocessing and advanced plutonium-bearing fuel fabrication technologies are sensitive and subject to technology transfer export controls.

Questions submitted by Representative Michael M. Honda

Q1. The House report language mentions the West Valley reprocessing plant. How much has it cost to clean up the reprocessing waste left over from operation of West Valley from 1966–1972? How much is it expected to cost? How long will the clean-up take?

A1. The Department's cost from the 1980 inception of the West Valley Demonstration Project (WVDP) through 1996 was $1.1 billion and included design, construction and initiation of hot operation of the high-level waste vitrification facility. Since 1997 (when the Office of Environmental Management began formally collecting cost information) through Fiscal Year 2004, the Department spent an additional $832 million (current year dollars). Per the WVDP Act (P.L. 96–368, 1980), this represents the Federal Government's contribution of 90 percent; the State of New York contributes 10 percent.

The Department plans to address its responsibilities under the WVDP Act in two phases. The preliminary estimated cost to complete the first step (associated with interim end state completion on or before 2010) is an additional $443 million for a total of $1.275 billion since 1997. The scope associated with this phase of the work includes completion of off-site low-level and transuranic waste disposition, and decontamination and demolition of facilities previously utilized to support tank waste solidification. The preliminary cost estimate associated with storage, surveillance, and monitoring of the vitrified waste canisters through 2035 (when off-site disposition is planned for completion) is $390 million.

The second step includes tank decommissioning. DOE and the State of New York are jointly developing an Environmental Impact Statement (EIS) for Decommissioning and/or Long-term Management of the West Valley Demonstration Project to evaluate various options for the site, including the technical, cost, and schedule considerations. The cost estimate and schedule associated with this final phase of the WVDP will be developed based on the outcome of the EIS, to be published in 2008.

Q2. Do you have an estimate of what it would cost to implement the plan proposed by Chairman Hobson to reprocess 50,000 metric tons of commercial nuclear waste at one or more Department of Energy (DOE) sites?

A2. No, the Department does not have an estimate for these costs. This is a very large undertaking and the Department is pursuing order of magnitude estimates during FY 2006.

Q3. Is the estimate for reprocessing of $280 billion from DOE's roadmap over 117 years still current? What fraction of this cost estimate was from reprocessing? Does this include cost for physical protection and safeguards of plutonium created? What design basis threat is assumed? Are you assuming a 9/11 magnitude threat in these estimates?

A3. These cost estimates are out of date. New technologies are under development that would represent a fraction of the costs that were estimated in 1999 with different technologies.

Q4. What are the principal technological uncertainties related to the development of the UREX+ process?

A4. While there are five technology variations under the UREX+ technology, the Department believes that one of these variations is most advantageous from a proliferation resistance perspective (in that it does not separate pure plutonium or separate pure plutonium plus neptunium). For that reason, most of the research and development is expected to be focused on that variation.

Q5. On page 4 of your testimony you state that commercial scale-up of spent fuel technologies could be accomplished relatively rapidly if existing domestic facilities could be modified and used. Where are these facilities and who owns them?

A5. There are four such facilities that could possibly be used in demonstrating the technologies. Two are private facilities built in the 1970s but never completed or operated with spent fuel. One is the Barnwell plant on the edge of the DOE Savannah River Site in South Carolina, designed and built by the Allied Chemical Company. The second is the General Electric Company's Morris Plant, at the edge of the Dresden Power Reactor south of Chicago, which is an active fuel storage facility containing about 800 tons of spent fuel originally slated for processing in the plant.

The other two facilities are at DOE sites: Savannah River Site and the Idaho National Laboratory (INL). The Savannah River facility is known as the H Canyon, previously used for processing spent reactor fuel for weapons purposes and now used as part of the site cleanup. The INL facilities are at the Idaho Nuclear Technology and Engineering Center (INTEC), consisting of several buildings previously used or intended to be used to process spent naval nuclear reactor fuel.

Q6. How will DOE select a reprocessing technology for the future? What factors will be taken into account?

A6. The selection of a reprocessing technology is dependent on economics, reliability, ease of scale-up and considerations related to safety and proliferation resistance. Advanced aqueous processing are best suited to treat spent nuclear fuel being stored and generated today and therefore are the technologies likely to be selected for reprocessing of those fuels. Pyrochemical processes may be better suited for spent fuel from advanced fast reactors.

Q7. Does the use of MOX fuel in light water reactors in conjunction with reprocessing actually reduce the amount of waste that will ultimately need to go into Yucca Mountain from the existing fleet of reactors in the U.S.? Please provide some specific numbers to illustrate your answer.

A7. The present technical capacity of Yucca Mountain is limited not as much by the amount of waste, but rather by the long-term heat produced by the waste and certain repository design restrictions. The principal sources of long-term heat are the transuranic elements in the waste. The most important of these are plutonium–241, americium–241 and neptunium–237. Aqueous reprocessing and the recycle of plutonium/neptunium into a modified form of MOX fuel to light water reactors can be used to transmute the critical transuranic isotopes and eliminate uranium (95 percent of the spent fuel by weight) from the final waste going to the repository. Therefore, by using these two processes together, it is possible both to decrease the amount of waste and to increase the technical capacity of the repository by a factor of about two.

Q8. Is MOX a U.S. technology? If MOX is used, will the U.S. have to pay royalties to the owners of the technology?

A8. The MOX technology was originally developed in the United States and therefore the U.S. would not need to pay royalties if MOX technology is used.

Q9. Does reprocessing itself create additional waste? If so, what is it?

A9. Reprocessing using a technology such as UREX+ would not create additional liquid high level waste as is associated with current generation PURER technology. The purpose of reprocessing is to reduce the total quantity of high level waste requiring repository disposal as compared with direct disposal of the same fuel. The French reprocessing experience with the PURER process has demonstrated a factor of four reduction in waste volume. Advanced aqueous recycling processes under development in the Advanced Fuel Cycle Initiative (AFCI) program have the potential for further volume reductions. This is because the high level waste would not have short or long term heat producing isotopes and therefore, would be superior to the PURER technology.

Q10. Are there other ways to burn nuclear waste in a reactor than MOX? What are they?

A10. MOX is the only fuel technology that has been commercially deployed for light water reactors. Research has been ongoing for several advanced technologies:

- Multi-recycle schemes based on MOX fuels have been investigated that provide greater benefits than the standard MOX approach, but come at a cost of significant difficulties in designing and operating fuel cycle plants.
- Advanced fuels, called Inert Matrix Fuels, that contain no uranium are being investigated and could provide additional benefits beyond MOX fuel. However, the development of Inert Matrix Fuels is not sufficiently advanced for commercialization.

Q11. Can high temperature gas cooled reactors burn nuclear waste after it has been reprocessed? If a gas cooled reactor is built at the Idaho National Lab, could it be used to demonstrate another means of getting rid of nuclear waste?

A11. Spent fuel from existing light water reactors contains plutonium and other transuranic elements (higher actinides) which are the most important contributors to the long-term radiological hazards and performance uncertainties for a geologic repository. Reprocessing can be used to separate these isotopes, which can then be fabricated into fuel for light water reactors or gas cooled reactors. By burning this fuel, thermal reactors (light water and gas cooled reactors) could destroy higher actinides, the plutonium.

Q12. DOE has many nuclear related issues that must be addressed including nuclear waste, non-proliferation, building new reactors in the near term, Gen IV reactors, rebuilding nuclear capability and industry in the U.S., nuclear hydrogen production and so on. I have the sense that many of these issues have been treated as unrelated and that there has not been an effort to take a systems view at DOE of these opportunities and issues. Is this the case? Would there be benefits from trying to see whether certain technologies or strategies would address two or more of these issues?

A12. The Department agrees that an integrated approach is needed to address the front and back end of the nuclear fuel cycle as well as reactor technologies. To that end, the Department has employed a systems approach to its research, specifically treating the issues such as waste minimization, energy optimization, proliferation resistance, economics and safety in an integrated fashion. The performance criteria associated with Generation IV reactors are closely coordinated with the advanced fuel cycle research and development. For example, as part of the fuels development effort, the Department is pursuing fuels that are proliferation resistant and recyclable, and are integrating the research and development on the fuels to meet both fuel cycle and reactor performance requirements.

In addition, in FY 2006, the Administration is proposing to commission a comprehensive review of NE program goals and plans by the National Academy of Sciences. The evaluation will validate the process of establishing program priorities and will result in a comprehensive and detailed set of policy and research recommendations, including performance targets and metrics for an integrated agenda of research activities.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Matthew Bunn, Senior Research Associate, Project on Managing the Atom, Harvard University, John F. Kennedy School of Government

Questions submitted by Representative Michael M. Honda

Q1. If the United States made a decision to proceed with reprocessing its commercial spent nuclear fuel what impact would that have on our efforts to limit the spread of reprocessing and enrichment technologies around the world, and convince other countries not to pursue this technology themselves?

A1. If the United States undertakes large-scale reprocessing of its own commercial spent nuclear fuel, it will become significantly more difficult to convince other states that it is not in their national interest to pursue similar technology. The United States will have little ability to ensure that other states adopt proliferation-resistant approaches to reprocessing. Thus, the effort to stem the spread of reprocessing technology, a key element of President Bush's nonproliferation strategy, could be significantly undermined. At the same time, the magnitude of this effect should not be overstated; there are only a limited number of countries that do not already have operating reprocessing capabilities but are interested in establishing such capabilities (or might plausibly become interested in the next decade). Over the longer-term, the effect might be more significant.

Q2. It is vital to ensure that plutonium already separated by reprocessing is adequately secured against terrorist theft. What more should the U.S. Government be doing to ensure that nuclear stockpiles around the world are secure and accounted for and cannot fall into terrorist hands?

A2. A sea-change in the level of sustained White House engagement focused on sweeping aside the bureaucratic and political obstacles to rapid progress in locking down the world's nuclear stockpiles is urgently needed. An accelerated and strengthened effort would have many ingredients, but three are essential:

- accelerating and strengthening the effort in Russia, where the largest stockpiles of potentially vulnerable nuclear materials still exist, with the goal of ensuring that *all* nuclear weapons and weapons-usable materials there are secure enough to defeat demonstrated insider and outsider threats in Russia by the end of 2008, in a way that will last after U.S. assistance phases out;
- removing the potential bomb material entirely from the world's most vulnerable sites (particularly research reactors fueled with highly enriched uranium), with the goal of removing nuclear material or providing highly effective security for all of the most vulnerable sites within four years, and eliminating the civilian use of highly enriched uranium worldwide within roughly a decade; and
- building a fast-paced global coalition to improve security for nuclear weapons and weapons-usable nuclear materials around the world, with the goal of ensuring that every nuclear weapon and every kilogram of weapons-usable nuclear material, wherever it may be in the world, is secure and accounted for.

In addition to securing nuclear material at its sources—the critical first line of defense—strengthened efforts are also needed to beef up the inevitably weaker lines of defense that come into play after a nuclear weapon or nuclear material has already been stolen, including particularly strengthened police and intelligence operations (including sting operations and the like) focused on preventing nuclear smuggling and identifying potential nuclear terrorist cells.

The effort to lock down nuclear stockpiles around the world should be considered a central part of the war on terrorism. Homeland security begins abroad; wherever there is an insecure cache of potential nuclear bomb material, there is a potentially deadly threat to the United States. As Senator Richard Lugar (R–IN) has argued, the war on terrorism cannot be considered won until all nuclear weapons and weapons-usable nuclear materials worldwide are demonstrably secured and accounted for, to standards sufficient to prevent terrorists and criminals from gaining access to them.

President Bush should issue a directive identifying prevention of nuclear terrorism as a top national security priority, and appoint a senior official, with the access needed to get a presidential decision whenever necessary, to lead the many disparate efforts now underway to keep nuclear capabilities out of terrorist hands. A detailed set of recommendations is available in *Securing the Bomb 2005: The New Global Imperatives,* available on-line at http://www.nti.org/cnwm.

Q3. You state in your testimony (p. 8) that if the government is fulfilling its obligation to take title to spent fuel and clear progress is being made on the waste repository then potential investors in nuclear plants will have sufficient confidence to make a commitment. Given that the repository is about 10 years late in opening the government has yet to take possession of significant volumes of fuel, how much longer do you believe investors will give the benefit of the doubt to the government that it will ultimately fulfill its contractual obligations to take possession of existing spent fuel and open a permanent repository?

A3. From the perspective of a potential investor in a new nuclear plant—or the owner of an existing one—the most important thing is that the spent fuel must not become an indefinite political and economic liability hanging around the neck of the privately owned plant. If it was clear that the government was going to pay all the costs of the fuel's storage, or better yet, take it to an off-site location (for example, an interim storage facility), that would address the most important investor concerns; what happens to it after that, whether reprocessing or storage followed by direct disposal, is less critical from the investor's point of view.

Indeed, a decision to reprocess U.S. spent nuclear fuel would be more likely to undermine than to strengthen investor interest in new nuclear power plants. Reprocessing would be significantly more costly than direct disposal, meaning that either (a) the nuclear waste fee would and would have to be substantially increased; (b) the government would have to pass onerous regulations forcing industry to build and operate facilities that would not be economic in themselves; or (c) the government would have to provide many billions of dollars in subsidies for this approach to spent fuel management. From the point of view of a potential investor in nuclear power, options (a) and (b) are quite unattractive, and whether the government would actually fulfill its obligations in option (c) is, if anything, *more* uncertain than Yucca Mountain (and a permanent repository would still be needed in any case). Moreover, it is clear that reprocessing would provoke substantial political controversy in the United States, which would also be a negative from an investor's perspective. If we want nuclear energy to have a bright future, we need to make it as cheap, as simple, as safe, as proliferation-resistant, and as non-controversial as possible, and near-term reprocessing points in the wrong direction on every count.

In short, the government must meet its contractual obligations, but that does not help make the case for reprocessing of the fuel. The actual cost of storage of U.S. spent fuel for another decade—to the utilities, or to the government—is actually quite modest; estimates that storage will cost the government $1 billion per year are vastly overstated. That being said, it is important, regardless of what decisions are made about reprocessing, to move forward in a timely way with licensing and opening a permanent repository.

Q4. You note that the Department of Energy (DOE) has not performed a credible life cycle cost analysis of the cost of a reprocessing and transmutation system compared to that of direct disposal. Do you recommend that the Committee direct DOE to conduct such an analysis? Is that a necessary first step, in your opinion?

A4. Such an analysis is certainly needed, but it should be only one part of a broader assessment of the costs and benefits of near-term reprocessing, compared to interim storage followed by direct disposal. If advocates argue that separations and transmutation are needed to make more repository space available, then a credible study is needed—which does not yet exist—of *all* the available options for achieving that goal, with their costs, risks, and benefits, not just of reprocessing. If advocates argue that separations and transmutation will reduce the toxicity and lifetime of the waste to be disposed, then a credible study is needed—which does not yet exist—of the total life-cycle environmental hazards posed by direct disposal compared to those of separations and transmutation (including near-term doses from operations of the relevant facilities, not just long-term doses from a permanent repository, and including not only doses from normal operations but from plausible accidents as well). In the post-9/11 era, detailed analyses of the terrorist risks of both approaches are needed, and these, too, have not yet been done. No realistic evaluation of the impact of a reprocessing and transmutation on the existing nuclear fuel industry has yet been done. No serious evaluation of the licensing and public acceptance issues facing development and deployment of a separations and transmutation system has yet been done. No serious assessment of the safety and terrorism risks of a reprocessing and transmutation system, compared to those of direct disposal has yet been done. Assessments of the proliferation implications of the proposed systems that are detailed enough to support responsible decision-making have not yet been done. In short, virtually none of the most important information on which to base a responsible decision to carry out reprocessing of U.S. nuclear fuel is yet available. The Committee should consider directing DOE to carry out studies of all these matters, or assigning such studies to the National Academy of Sciences. In either case, the Committee should allow enough time for careful consideration of the relevant issues.

Q5. You recommend the establishment of expanded interim storage facilities "as a complement and interim backup" to the Yucca Mountain repository. Is there any reason why that interim facility shouldn't also be located at Yucca Mountain?

A5. The area around Yucca Mountain is one plausible location for such an interim facility, but there are others, and the different possible locations have both advantages and disadvantages. Obviously, there are advantages to shipping the fuel to a site close to where it will ultimately be disposed of. There are also disadvantages, however. Technically, the area around Yucca Mountain has a high level of seismic activity, which is more of a problem for an above-ground interim storage facility than a below-ground repository (just as a storm at sea is more of a problem for surface ships than for submarines). Politically, Congress has in the past judged that it would not be fair to burden Nevada with both the permanent repository and an interim storage facility. For any interim site, detailed analysis of the best approaches to providing safe and secure transportation of spent fuel to the site is needed, and such analyses may reveal that some sites have significant safety or security advantages over others.

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November 16, 2005

The Honorable Judy Biggert
U.S. House of Representatives
1317 Longworth House Office Building
Washington DC 20515

Dear Representative Biggert:

I believe the Subcommittee's Questions for the Record lie beyond the scope of the American Physical Society report (and generally beyond my own area of expertise), particularly on the issue of the economics of reprocessing. So, on the behalf of the APS report, we cannot offer a response to the questions.
As noted, I am uncomfortable with providing detailed answers to the questions raised on the basis of expertise in the economics, however I can offer a few personal observations based on my general experience that may be useful. These are not intended to reflect the position of APS.

The economics of reprocessing is a very complex issue that is tied to a variety of components other than the free market.
In the long term:
A. Current Fuel Cycles:
Greater use of nuclear energy on a global basis will increase demand for fuel for reactors of the light water variety. Spent fuel contains fissile plutonium that has a "value" to the light water cycle roughly equal to enriched uranium, some \$10K's per kilogram. In this way, a light water reactor is a "converter" making about 60% of the fissile material it uses by creating plutonium from the non fissile uranium that makes up most of the core. The traditional argument for reprocessing is to capture the energy value (and economic value) of the fissile plutonium. In a world where nuclear energy becomes more fully utilized, reprocessing is a natural evolution to assure maximum utilization of all available energy supplies. Regardless of the U.S. decision, it is expected that international reprocessing will be part of the growing world role of nuclear energy. The POPA report indirectly recognizes this in suggesting the U.S. carefully consider methodologies for reprocessing (in the U.S.) that would be most resistant to proliferation in the hopes of influencing directions through U.S. leadership. There may be some technical approaches that are more resistant (which is why POPA suggested more work before a decision), but international control and supply management mechanisms may, in the end, be the best choice (e.g. full cycle guarantees with reprocessing and enrichment only done in "safe states")
B. Future Fuel Cycles:
Future generations of nuclear power plants may use fuels that have higher concentrations of fissile material (enriched uranium and plutonium 239). The economics of these fuel cycles strongly favors "breeding" (producing more fissile material than is used) and recapture and

concentration of plutonium from existing reactors. If nuclear energy evolves along the line of Gen 4 or other advanced concepts, some form of reprocessing will be required and will be expected to be needed in a number of countries. There is no economic argument for these new concepts that would favor enrichment over reprocessing. Likely, both will be needed.

The POPA report was intended to encourage U.S. government leadership in shaping the advanced nuclear fuel cycle to minimize potential for proliferation.

C. Increased Waste Storage Capacity:

In general, the recycle of fuels (reprocessing) allows for greater concentration of spent nuclear fuel. Unless a very expensive (and economically unattractive) isotopic separation or transmutation process is used, reprocessing is the way that the quantity of spent fuel can be reduced for the current generation of light water reactors. POPA was told that Yucca Mountain's capacity for spent fuel could be increased significantly (up to a factor of two) through reprocessing, which would allow expansion of the use of nuclear energy in the U.S. without developing another repository.

POPA recognizes that there are some legal issues involved with licensing new reactors without expansion of national waste capacity, but our technical judgment was that there is adequate time and potential for technology to address the issue.

D. Uncertainty in Economics:

The economics of nuclear energy is completely distorted by the government's role and actions. Critics argue the role of government in supporting the industry especially in the development of technology calling the industry the most subsidized energy component. Supporters argue that the cost of nuclear energy has been badly distorted by unnecessarily burdensome regulations and the inability to move forward predictably on waste disposition and licensing. There appears to be elements of truth and distortion in both views. In a more strategic sense, concerns about the dangers of a more nuclear world (e.g. proliferation) and environmental sensitivity around the volatile (and psychologically scary) issue of long lived nuclear waste continues to make a firm plan for the future of nuclear energy problematic.

Perhaps the most important factor in answering the economic questions raised is the uncertainty of the regulatory environment (federal and state) and federal policy in general. Under the circumstances, it is hard to give a sound answer to economic/market questions involving nuclear energy in the U.S. since the industry has not been able to set cost/return points for reactors for decades, let alone new reprocessing and production plants.

As a final thought, a review of "megaprojects" of the 20th Century will show that no major technically complex project in the \$B's has been completed on the budget proposed at inception. Rather they run an average of some 30% or more over the original budget, making cost estimation for reprocessing problematic, perhaps within a factor of two.

Sincerely,

Roger Hagengruber

Roger Hagengruber
Chair, Nuclear Energy Study Group, APS
Director, Institute for Public Policy, UNM

ANSWERS TO POST-HEARING QUESTIONS

Responses by Phillip J. Finck, Deputy Associate Laboratory Director, Applied Science and Technology and National Security, Argonne National Laboratory

Questions submitted by Chairman Judy Biggert

Q1. There was some discussion during the hearing about the economics of reprocessing, once it becomes commercial scale. What are the major steps necessary before the technology is mature enough for commercial deployment? For each of those steps, do we have enough information to estimate the associated costs? If so, what are the costs?

A1. The UREX+ aqueous reprocessing technologies have already been demonstrated at the laboratory scale with spent nuclear fuel. As these processing technologies are similar to the mature PUREX process currently being used in France and the United Kingdom (U.K.) at an industrial scale, it is likely that scale-up to industrial size will be successful and relatively straightforward if similar equipment is used. If advanced equipment, reducing size and cost, is desired, then an intermediate stage of pilot plant demonstration would be prudent, and represents the only major step in development. The UREX+ technologies are candidates for processing spent fuel from light water reactors (LWRs), typical of present-day nuclear power plants.

Less developed technologies, such as pyroprocessing, should be viewed as being further from commercialization at an industrial scale. Ongoing research and development of this method in the DOE Advanced Fuel Cycle Initiative (AFCI) program is aimed at facilitating the large-scale commercialization of this technology as well. However, at this time, the likely use for pyroprocessing is to process spent fuel from fast neutron reactors that are used for actinide transmutation and uranium resource extension. Since the U.S. currently does not have any reactors of this type, but would likely implement them in the future as part of an overall energy strategy, there is sufficient time for this technology to mature.

The proposed Advanced Fuel Cycle Facility in the AFCI program would address the need for pilot scale demonstration of both UREX+ and pyroprocessing. Results from testing in this facility should allow the competent design of industrial facilities using these technologies. While cost estimates for such a facility are necessarily highly uncertain, due to the lack of recent experience in building such a facility, it is likely that the current cost estimate for this facility would be in the range of $1B (including not only processing demonstration but fuel fabrication capabilities as well), with an estimated annual operating cost to demonstrate these technologies of $100M/year. Although admittedly large, these costs need to be placed in the context of the existing nuclear power industry in the United States, with capital investment of several hundred billion dollars, and electricity generation of about $50B or more per year. Payments into the nuclear waste fund also approach $1B per year, with the anticipated cost of the Yucca Mountain repository in the neighborhood of $50B.

Questions submitted by Representative Michael M. Honda

Q1. The House report says that European countries "recycle" (plutonium) as they go, but actually MOX fuel is not made and used immediately. (Nor is the high-level liquid waste generated from reprocessing immediately vitrified; rather it is stored in stainless steel tanks to cool.) More than 200 metric tons of commercial plutonium worldwide is separated and has not been used as MOX and the surplus is building up each year. Many reactors need costly modifications to use MOX and some reactors cannot be modified. There are about 80 metric tons of surplus plutonium at La Hague in France and similar amounts at Sellafield in the United Kingdom (U.K.) and more than 30 metric tons in Chelyabinsk, Russia. The UK has no reactors which can use plutonium fuel and no operating MOX factory. How can you explain that this is a recycling program when the UK has amassed about 80 metric tons of civil weapons-usable plutonium and has no plans to use this material? (For Pu amounts reported to the International Atomic Energy Agency (IAEA)—see INFCIRC 549, on IAEA web site.)

A1. At this time, there is a mismatch in the ability to process commercial spent fuel and the ability to re-use the separated materials in reactors, both in Europe and elsewhere. As a result, substantial stockpiles of separated materials have been accumulated, although that was not the original intent. In France and other countries, the spent fuel processing activity was intended to be part of an integrated system where the recovered plutonium would be used in thermal and fast reactors. However, due to shifting program emphasis and priorities, the construction and operation of the processing plants has proceeded mostly as planned, while the reactor systems to use the plutonium have not. A similar situation also exists in the U.K. and in Russia, for basically the same reason.

One can ask why the current situation has developed, and the answer is probably found in a combination of factors. First, electricity demand, and hence reactor construction, did not grow as envisioned, but stagnated instead, driven mainly by large improvements in efficiency for a wide variety of electricity-driven products, including electronics, appliances, etc., and by a drop in heavy industrial use. Second, opposition to the use of nuclear power increased dramatically in the wake of the Three Mile Island and Chernobyl accidents. This opposition exacerbated the situation, leading to the large mismatch in capabilities that exist today. Other minor reasons can also be cited, but the point is that when the plans were originally conceived, the systems were intended to balance, and achieve the "recycle as they go" condition.

That being said, it should be noted that France is engaged in recycling the plutonium in those reactors capable of using this material. Newer reactor designs are intended to allow for increased use of MOX fuel, which should address the stockpile concern as these reactors are constructed and brought into service to replace reactors being decommissioned. The situation in the U.K. and Russia is different, where the future direction of nuclear power has still not been decided. Until the time that these countries decide to adopt plutonium recycling as originally planned, or another disposition path is taken, the accumulated stockpile of separated plutonium will continue to exist with no specified purpose, and should be considered as either a resource for the future or as a separate waste stream for eventual disposal. The Russian position has been made quite clear many times: they regard separated plutonium as a valuable energy resource and plan to utilize this material in the fast reactors that are planned for deployment in the future.

It is correct that many reactors would need costly modifications to use MOX, and some cannot be modified to use MOX. But it is also correct to state that many reactors are ready to use MOX with only minor and no modifications. Furthermore, I believe that the U.S. should move towards a close fuel cycle, where the MOX approach would be at best of limited relevance; this approach would involve the transition towards a new generation of fast reactors, with novel fuel types and separations techniques, that would eliminate a very high fraction of radiotoxic elements.

Q2. France uses plutonium fuel (MOX) in 20 out of 58 reactors, but the stockpile of civil plutonium continues to increase with no end in sight. How can this growing stockpile be presented as "recycling"? MOX fuel produces only about 15 percent of France's nuclear electricity and imposes about $1 billion per year in added electricity costs, according to an official French report. Why does Electricite de France, the state-owned utility forced to use MOX fuel, place a negative value on plutonium they must take from the state-owned processing company (Cogema)?

A2. I am, of course, not able to speak for the French utility industry. As to the question of recycling, the fact is that the recovered plutonium is being recycled, but that the rate of recycling is lower than the design rate of production at the processing plant. As more reactors become available to use the MOX fuel, this mismatch in production and demand will diminish, and eventually reverse, gradually consuming the current stockpile of separated plutonium. This would be consistent with the original intent of the French planning, but it has not yet been put into place.

The question of the added cost would need to be examined carefully to determine what is included and what is not included. The negative value on plutonium compared to standard enriched uranium fuel appears reasonable, as any fuel made from separated materials is likely to cost more than enriched uranium fuel as long as uranium ore costs remain low—it is not at all clear that this situation will remain stable for the foreseeable future. Basically, enrichment to the required level is currently cheaper than fuel processing, separation, and MOX fabrication. However, this probably does not account for the changes that have been made in the resulting waste stream. In France, and in other countries, such an accounting may be difficult, as no waste disposal strategy has been determined. Without a strategy in place, one cannot place a value on the reduction in waste volume and toxicity arising from spent fuel processing. Depending on the ultimate cost of disposal, the cost savings from the reduced amount of waste may be sufficient to offset or even exceed the additional costs of processing, or they may not. It is important to realize, though, that these costs still only represent a minute fraction of the cost of generating nuclear electricity, and when one examines the value of pursuing a given strategy, such as plutonium recycling, the entire system must be considered, from mining to geologic disposal.

Q3. *Japan is in the start-up phase of a massive new $20 billion reprocessing factory (Rokkasho). Its reprocessing program is estimated to cost $166 billion over 40 years (including construction, operating, and decommissioning costs). Japan has committed itself to keeping its plutonium supply and demand in balance but Japan already has 40 MT (35 MT in Europe, five MT domestic) supply of plutonium. How can operation of Rokkasho and failure to implement a domestic MOX program be presented as balancing supply and demand? Especially when the utilities are wary of the program? Japanese politicians have spoken in recent years of making a weapon and one has suggested that Japanese commercial plutonium stocks could be used to make large numbers of weapons. What would this mean for global non-proliferation measures? What would this mean for stability of the region?*

A3. It is highly desirable to construct and operate a reprocessing plant with the plant being part of an integrated system, where the recovered materials are quickly re-used in nuclear reactors. This is why the need for an integrated system is stressed, and one needs to either implement the entire system, or to not implement anything. It is surely the intent of the Japanese to re-use the recovered plutonium in their nuclear reactors to help increase the security of this part of their overall energy supply, although it would appear that there was not agreement by all parties involved in the government and industry as to how and when this would be accomplished. As to why the Japanese utilities are wary of the program, it is difficult to say why without explicit statements on their part. Presumably a great part of this concern is the uncertainty in future fuel cycle costs; this is countered to a degree by the assurance of a domestic fuel supply in a world economy in which the price of uranium may increase significantly.

Although some Japanese politicians have spoken about constructing a nuclear weapon, I believe that the context for such comments is likely to be in response to what the Japanese perceive as an increasing instability in the region due to the recent actions of China and North Korea. As a result, comments about global non-proliferation and the impact to the stability of the region are probably best left to the diplomats.

It does need to be noted, however, that the Japanese commercial plutonium stocks are already ill-suited for weapons use, and is part of the reason that civilian reprocessing activities are only marginally related to the issue of non-proliferation. Plutonium obtained from commercial spent fuel with a typical amount of irradiation in the reactor not only has an isotopic composition that makes weapon fabrication problematic (although not impossible), but storage of this plutonium leads to further degradation such that the plutonium would need to be refined again before weapons use could even be contemplated. It is likely that such refining may be necessary for the fabrication of new nuclear fuel as MOX, depending on the storage time. This is one reason why a mismatch between spent fuel processing rate and the ability to use the separated plutonium is undesirable, and should be avoided if possible.

Q4. *Dr. Finck, in your presentation before the Advanced Fuel Cycle Initiative's Semi-Annual Review Meeting in August of 2003, you stated that, "Expect that proposed dual tier fuel cycle cannot be made intrinsically proliferation resistant." Why don't you consider UREX-plus proliferation-resistant? What are the issues here?*

A4. I do stand by my statement of 2003. Nevertheless, I never stated that UREX-plus is not proliferation resistant.

The use of dual tier systems requires that relatively pure streams of Plutonium and Neptunium be separated from the Spent Nuclear Fuel, as Light Water Reactors have a limited ability to recycle other materials such as Americium and fission products. That clean separated material can be viewed as a proliferation concern. Nevertheless, the same system can be made proliferation resistant by the use of advanced safeguards measures, which are currently being vigorously pursued in the AFCI program. Furthermore, the single tier system, that does not utilize recycle in thermal reactors, but directly transmutes elements in fast reactors, can accommodate much less pure mixtures of elements, and therefore presents interesting proliferation resistance attributes. Even in this system, we would insist on the incorporation of advanced safeguards features in fuel cycle facilities.

Q5. *You state in your testimony that nuclear energy could produce process heat that could be used in the production of transportation fuels such as hydrogen. However, you also included synthetic fuel in the product slate. What synthetic fuels would be possibly produced at a nuclear plant?*

A5. I apologize if my inclusion of synthetic fuels in the product slate has created some confusion. The application of nuclear power to the production of synthetic fuels is to provide either process heat, electricity or hydrogen, to a plant that is making synthetic fuels from other feedstocks such as coal or gas. The synthetic fuels are basically the same concepts that were heavily investigated in the 1970's in response to the energy crisis at that time, and include coal gasification and liquid synfuels.

Q6. In your statement (p. 1–2) you say that the U.S. needs to take a more comprehensive approach to nuclear waste management and you mention that resource optimization and waste minimization as two objectives that must be pursued with targeted R&D to minimize their economic impact. With respect to waste minimization, what is the potential for reducing the volume and/or heat contained in the waste? What are the tradeoffs necessary to achieve maximum waste reduction?

A6. For the Yucca Mountain repository, the utilization of space in the repository is constrained by the amount of decay heat generated in the spent fuel. If this fuel is processed, and the actinide elements are removed along with the fission products cesium and strontium, it is possible to reduce the decay heat of the resulting waste by a factor in excess of 200. This can be used to greatly increase the utilization of the Yucca Mountain repository in terms of the amount of space needed to store the waste resulting from the production of a given amount of energy. At the same time, a lower total inventory of hazardous materials is placed in the repository as compared to the current plan for direct disposal of spent fuel, postponing the need for consideration of a second repository until the next century or beyond.

Processing of the spent fuel removes the uranium, which accounts for over 95 percent of the waste volume. Removal of the other actinide elements accounts for another two percent, while the cesium and strontium would account for about two percent. As a result, less than one percent of the original spent fuel material remains for disposal. The volume required to dispose of this material depends on the waste form, and is a current area of research. It is anticipated that about a factor of 50 to 100 reduction in waste content for a given amount of energy production can be achieved, perhaps greater. This would translate into an equivalent increase in the utilization of space in the Yucca Mountain repository.

There are not any "tradeoffs" required to achieve these reductions, although all of the removed materials need to be treated in some manner and in some respects that can be viewed as the tradeoff: any materials that are removed need subsequent treatment. The higher actinide elements can be efficiently recycled in nuclear reactors, preferably fast neutron reactors, and can be recycled as many times as required to consume the more troublesome elements. The separated fission products, cesium and strontium, can be placed in separate storage for 100–300 years to allow sufficient decay, and then disposed in the repository with no additional impact. Lest this sound like an unreasonably long time, it is useful to remember that some spent fuel has already been in storage for almost 50 years.

Q7. You assert that with a "significant R&D effort" new forms can be developed that can burn up to 50 percent of the plutonium and neptunium present in the spent nuclear fuel. What are the R&D challenges to being able to achieve a burn rate at this level?

A7. These consumption amounts in a single irradiation in a light water reactor can only be achieved with the development of what is known as "inert matrix fuel" or IMF. This fuel consists only of recycled materials, and uses an inert matrix material for the rest of the required fuel volume instead of using additional natural or depleted uranium. In this way, further creation of higher actinide elements from the uranium is avoided, and the recycled materials provide the only fission sources. The R&D challenges center on the development of an appropriate inert matrix material, which has become more complicated as explained in the next paragraph. This approach was briefly in favor for certain applications, such as the destruction of weapons-grade plutonium, and has been examined in the DOE AFCI program as a potential approach for recycling the higher actinide elements.

However, detailed studies have shown that the IMF approach does not provide substantial benefits either to waste management or resource utilization by itself, but would also need to be recycled to provide the opportunity for greater benefits. The major difficulty is in formulating an inert matrix that can be reprocessed easily, and is the subject of some ongoing research. It should be noted, though, that even if such a fuel form can be developed, the utility of the IMF approach is greatly inferior to that of the fast neutron reactors. For this reason, the IMF approach is not being actively considered for either the single tier or dual tier strategy. An advanced LWR with MOX-type fuel can already be implemented as the first tier of the dual tier strategy with maximum overall benefit, and the IMF approach would not add to this benefit.

Q8. The U.S. has entered into an international framework agreement for the development of the Generation IV nuclear reactor. Is the reprocessing necessary for this reactor design covered under the agreement? If not, why not? What other countries are engaged in reprocessing R&D for the Gen IV reactors?

A8. The reprocessing activities associated with the Gen IV reactors are the same as are being discussed here, as are the advanced reactors being considered in the DOE AFCI program for a single tier or dual tier system. All of the fast reactor concepts that would be part of a two tier system are represented in the Gen IV program.

As for the other countries that are engaged in reprocessing R&D, virtually all of the members of the Gen IV International Forum are conducting research to one degree or another. The most active members in this area are France and Japan along with the United States. We have active technical collaboration agreements in place with a number of countries involved in the development of reprocessing technologies for advanced nuclear reactors.