# ADVANCING TECHNOLOGY FOR NUCLEAR FUEL RECYCLING: WHAT SHOULD OUR RESEARCH, DEVELOPMENT, AND DEMONSTRATION STRATEGY BE?

## HEARING

BEFORE THE

## COMMITTEE ON SCIENCE AND TECHNOLOGY
## HOUSE OF REPRESENTATIVES

ONE HUNDRED ELEVENTH CONGRESS

FIRST SESSION

JUNE 17, 2009

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**June 17, 2009**

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# ADVANCING TECHNOLOGY FOR NUCLEAR FUEL RECYCLING: WHAT SHOULD OUR RESEARCH, DEVELOPMENT AND DEMONSTRATION STRATEGY BE?

**WEDNESDAY, JUNE 17, 2009**

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
*Washington, DC.*

The Committee met, pursuant to call, at 10:06 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Bart Gordon [Chairman of the Committee] presiding.

BART GORDON, TENNESSEE
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RALPH M. HALL, TEXAS
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U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE AND TECHNOLOGY

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Committee on Science and Technology

Hearing on

# Advancing Technology for Nuclear Fuel Recycling: What Should Our Research, Development and Demonstration Strategy Be?

Wednesday, June 17, 2009
10:00 am. – 12:00 p.m.
2318 Rayburn House Office Building

**Witness List**

**Dr. Mark Peters**
*Deputy Associate Laboratory Director*
*Argonne National Laboratory*

**Dr. Alan S. Hanson**
*Executive Vice President for Technology and Used Fuel Management*
*Areva, Inc.*

**Ms. Lisa Price**
*Senior Vice President*
*GE-Hitachi Nuclear Energy and*
*Chief Executive Officer*
*Global Nuclear Fuel*

**Dr. Charles D. Ferguson**
*Philip D. Reed Senior Fellow for Science and Technology*
*Council on Foreign Relations*

HEARING CHARTER

## COMMITTEE ON SCIENCE AND TECHNOLOGY
## U.S. HOUSE OF REPRESENTATIVES

# Advancing Technology for Nuclear Fuel Recycling: What Should Our Research, Development, and Demonstration Strategy Be?

WEDNESDAY, JUNE 17, 2009
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

### Purpose

On Wednesday, June 17, 2009 the House Committee on Science and Technology will hold a hearing entitled: *"Advancing Technology for Nuclear Fuel Recycling: What Should Our Research, Development, and Demonstration Strategy Be?"*

The Committee's hearing will explore the benefits and risks associated with nuclear waste recycling and the research development and demonstration needed to address the technical challenges and policy objectives of a nuclear waste management strategy that could include recycling spent nuclear fuel. If nuclear power is going to expand in this country the government needs to have a strategy to manage the growing volumes of spent nuclear fuel. The Committee will hear from expert witnesses who will discuss the issues relevant to deployment of advanced technologies for nuclear waste recycling.

### Witnesses

- **Dr. Mark Peters is the Deputy Associate Laboratory Director at Argonne National Laboratory.** Dr. Peters will testify on the current research, development, and demonstration programs at the Department of Energy to advance technologies for recycling spent nuclear fuel. He will also discuss future RD&D needs.
- **Dr. Alan S. Hanson, Executive Vice President for Technology and Used Fuel Management at Areva, Inc.** Areva has worldwide operations that encompass the entire nuclear power cycle, including uranium exploration and mining, fuel fabrication, design and construction of nuclear reactors, and treatment and recycling of spent fuel. Dr. Hanson will provide information regarding Areva's technology for reprocessing nuclear waste and the company's technology development underway.
- **Ms. Lisa Price is the Senior Vice President, GE Hitachi Nuclear Energy and Chief Executive Office of Global Nuclear Fuel.** GE Hitachi develops advanced light water nuclear reactors and provides products and services for improving output and efficiency of existing nuclear power plants. Ms. Price will testify about General Electric's technology development for recycling spent nuclear fuel and GE's work with the Federal Government in this area.
- **Dr. Charles D. Ferguson is a Philip D. Reed Senior Fellow for Science and Technology at the Council on Foreign Relations.** The Council on Foreign Relations is an independent, non-partisan organization established in 1921 to explore foreign policy issues and promote an understanding of the U.S. role in the world. Dr. Ferguson will provide testimony about the various technology options available for management of spent nuclear fuel and the benefits and risks associated with those technologies.

### Background

According to the Nuclear Regulatory Commission (NRC), as of August 2008 there are 104 commercial nuclear power reactors licensed to operate in thirty-one states providing approximately 20 percent of our nation's electricity supply. The approximate 58,000 metric tons of spent nuclear fuel already existing at these reactor sites continues to accumulate at a rate of 2,000 metric tons per year. In 1987, Congress designated Yucca Mountain in Nevada as the Nation's sole candidate site for a permanent high-level nuclear waste repository. The Department of Energy submitted a license application to the NRC for the proposed Yucca Mountain site in June 2008. The *Nuclear Waste Policy Act of 1982* targeted 1998 as the year to start loading waste into the repository. That date has been pushed back repeatedly.

The Obama Administration is taking a very different approach to Yucca Mountain and nuclear waste management. President Obama is proposing to cut funding for the Yucca Mountain project by approximately $100 million and to convene a blue ribbon panel to look for alternative solutions for managing the Nation's nuclear waste. The President's 2010 budget request appears to continue the Yucca Mountain licensing process, but the significant funding cut certainly would delay the planned 2020 opening of the repository.

**Alternatives to Yucca Mountain**

Current law provides no alternative repository site to Yucca Mountain, and it does not authorize DOE to open temporary storage facilities without a permanent repository in operation. In the past, there have been discussions about the Department of Energy taking title of the commercial spent nuclear fuel and paying for the cost of storing the waste at the private utility sites. In the early 1980s the NRC determined that waste can be safely stored at these reactor sites for at least thirty years after a reactor shuts down. More recently, the NRC is proposing a further revision to its Waste Confidence Decision to find reasonable assurance that spent fuel can be stored safely for at least sixty years after a reactor's licensed operating life. In addition, under current law a private storage facility could be licensed by the NRC. Such a facility has been licensed in Utah, but its operation has been blocked because it cannot obtain a permit from the Department of Interior's Bureau of Land Management.

**Recycling Spent Nuclear Fuel**

With the Obama Administration poised to delay the Yucca Mountain project and initiate a major program review, recycling spent nuclear fuel is likely to be considered in part because there is another long-term concern that uranium supplies for nuclear fuel may become scarce if it cannot be reused. Along with consideration of a recycling alternative for nuclear waste management, it is essential to examine the research, development and demonstration needed at the federal level to ensure that we understand the safety, environmental, security and economic issues associated with a decision to adopt a nuclear waste recycling program in this country.

Since the 1970s, U.S. nuclear waste policy has been based on the "once through" fuel cycle in which nuclear fuel is used once in a reactor and then permanently disposed of in long-term storage. The major alternative is the "closed" fuel cycle, in which spent nuclear fuel would be reprocessed into new fuel. The goal is to extract more energy from a given supply of uranium, reduce the amount of waste going to a permanent waste repository and do this in a manner that is proliferation-resistant.

Fuel for U.S. nuclear reactors currently consists of uranium in which the fissile isotope U–235 has been enriched to three to five percent—the remainder being the non-fissile isotope U–238. During use in the reactor most of the U–235 splits, or fissions, releasing energy. Some of the U–238 is transmuted into fissile isotopes of plutonium, some of which also fissions. In reprocessing, the uranium and plutonium are chemically separated to be made into new fuel while the lighter elements resulting from the fission process are stored for disposal. There are a number of different fuel options for recycling nuclear waste. One process, used primarily in France, mixes plutonium with uranium to form fresh fuel known as MOX fuel which can be reused once in most existing light water reactors. For multiple recycling of spent fuel, advanced reactors would be necessary. These fast reactors could create new fuel from spent fuel repeatedly in a manner that would allow it to be fed back into the reactor until it is entirely fissioned. These fast reactors also would destroy the longest-lived radioactive components for the fuel, leaving only relatively short-lived radioactive isotopes which would decay to background levels within approximately 1,000 years. Ultimately, these short-lived isotopes would be sent to permanent storage.

Depending on the exact technologies chosen to close the nuclear fuel cycle, there are a number of issues to consider. The National Academy of Sciences, the General Accountability Office, and the Council on Foreign Relations have raised questions about using an approach such as the process used to form MOX fuel. This involves separating a pure stream of plutonium from the spent fuel, prompting concerns about proliferation of weapons-grade materials. Although still debated, spent fuel recycling could save space in an underground repository by reducing the near-term heat load, which is the primary limit on repository capacity. However, the closed fuel cycle is generally considered to be substantially more expensive than the once-through cycle and there is a broad scientific consensus that long-term isolation of nuclear waste from the environment will still be required. There is also widespread agreement that a more robust long-term research and development program is needed to address these outstanding issues.

Chairman GORDON. Good morning, and this hearing will come to order.

I want to welcome everyone to today's hearing to explore the policy questions and the research, development, and demonstration needs associated with recycling of spent nuclear fuel. I would like to welcome our expert panelists who will discuss the ongoing R&D activities in the Federal Government, private sector and around the globe and help us to understand the safety, environmental, security and economic issues related to the adoption of a nuclear reprocessing strategy.

I am supportive of nuclear power as I believe it is part of the solution to the daunting challenge of climate change and energy independence and I also recognize that our 104 operating reactors provide very reliable baseload power.

To me, the best reason to consider reprocessing is that an expansion of nuclear power may make the once-through fuel cycle inadequate for maintaining our nuclear power supply as uranium sources eventually become scarce. There are near-term technologies available for reprocessing spent nuclear fuel that could be deployed in the United States relatively quickly, but there are some well-documented concerns raised about this strategy. I am also aware of ongoing research in more advanced technologies that could address nuclear fuel cycle issues that we face today, and while reprocessing of spent fuel allows us to extract more energy from a given supply of natural uranium, it raises concern about increased costs for waste management and proliferation of weapons-grade materials.

I am hopeful that today's discussion will shed some light on the various benefits, challenges and risks that we must address before adopting a long-term nuclear recycling strategy.

As I told our witnesses earlier, we have a variety of hearings going on simultaneously. The bells are ringing, we may have votes, and we want to have as much of the hearing as we can. If it gets to a point where there is going to be a long lapse, we will try to be respectful of your time. I know you have prepared statements, and as you go through that, as much as you can I would hope that you later in the questions and answers try to help me with what I think is sort of my threshold question, at least one of the threshold questions, and that is, do we move forward with existing technologies to reprocess or do we skip that and wait for the next generation to come along? So part of that is, do we have storage now to wait for that next generation? Is that next generation really, you know, feasible, and what are going to be the cost consequences of that? So if you can in your materials, you might try to work that in.

Now I would like to recognize Dr. Ehlers for an opening statement.

[The prepared statement of Chairman Gordon follows:]

PREPARED STATEMENT OF CHAIRMAN BART GORDON

Good morning and welcome to today's hearing to explore the policy questions and the research, development, and demonstration needs associated with recycling our spent nuclear fuel.

I would like to welcome our expert panelists who will discuss the ongoing RD&D activities in the Federal Government, private sector and around the globe, and help us understand the safety, environmental, security and economic issues related to the adoption of a nuclear reprocessing strategy.

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I am hopeful that today's discussion will shed some light on the various benefits, challenges, and risks that we must address before adopting a long-term nuclear recycling strategy.

Again, I would like to thank the witnesses for their participation today and I look forward to your testimony. Thank you.

Mr. EHLERS. Thank you, Mr. Chairman, for holding this hearing today on nuclear fuel recycling. I am sitting in for the real Ranking Member, Mr. Hall from Texas, who is temporarily detained on the Floor and I am sure he will return shortly and spice up the reading with his inimitable sense of humor.

I am very pleased that you are holding this hearing, Mr. Chairman. I think it is a very important issue for this committee to be looking into as nuclear energy is a clean and reliable source of baseload power in the United States. Now, not everyone has agreed with that statement over the years, but back when nuclear power began to run into trouble in the United States with the environmentalists—and I am a staunch and always was a staunch environmentalist—I argued strenuously for nuclear power on the basis that it was the only method available then which would not contribute to greenhouse gases. Back in 1970, not too many people were worried about greenhouse gases. Today we worry a great deal about them.

But we all know the basic facts. There are currently 104 nuclear power plants in 31 States in the United States generating approximately 20 percent of the electricity produced. Nuclear plants in 2008 were at a capacity factor of 91.5 percent compared to 73.6 percent for coal, 42 percent for natural gas and 40 percent for renewables, and I understand Michigan has four nuclear plants and another one under construction. They currently generate 26.2 percent of the state's electricity, one of the highest of any states, I believe.

As the industry is facing resurgence and the interest to build new nuclear plants, the issue of nuclear waste is prevalent. That has always been one of the great deterrents to using nuclear energy. What is even more troubling is a decision by the Obama Administration to abandon a permanent repository at Yucca Mountain, Nevada, after over 20 years of research and billions of dollars of carefully planned and reviewed scientific fieldwork.

So we are here to receive testimony from our four expert witnesses on the facts and on the pros and cons of reprocessing and recycling used nuclear fuel. I believe that finding some sort of solution to how to handle our used nuclear fuel is critical to the continued successful contribution of nuclear energy to our country's electric generation and I look forward to hearing from today's witnesses on this important and timely topic.

I do regret, Mr. Chairman, that this committee has not had much to say about handling nuclear waste in the past. This in one of many issues which should be in our jurisdiction but has been in another committee. I think we may have written a better bill regarding Yucca Mountain, and I think the biggest problem is the way the bill was written. It was impossible to meet the requirements. No one could predict or prove that for 10,000 years there would be no leakage, whereas if we had taken the road of monitored retrievable storage with the ability to repair any casks that might leak, we would have been much further along at much less cost. That may or may not have been the best solution but certainly should have been examined. I have mixed feelings about the reprocessing approach. The cost is, as we know, very high, and won't really solve the problem in any better way than other things that we could do. I am very eager to hear the comments from the experts this morning and to find out just what we can do in terms of dealing with nuclear waste, what is proper and what is best, what is most economical and what other approaches might be available and useful.

With that, I yield back.

[The prepared statement of Mr. Ehlers follows:]

PREPARED STATEMENT OF REPRESENTATIVE VERNON J. EHLERS

Mr. Chairman, thank you for holding this hearing today on nuclear fuel recycling. I think this is a very important issue for this committee to be looking into as nuclear energy is a clean and reliable source of baseload power in the United States.

We all know the basic facts. There are currently 104 nuclear power plants in 31 states operating in our country generating approximately 20 percent of the electricity produced. Nuclear plants in 2008 ran at a capacity factor of 91.5 percent compared to 73.6 percent for coal, 42 percent for natural gas and 40 percent for renewables. My home State of Michigan has four nuclear plants that generate 26.2 percent of the state's electricity.

As the industry is facing resurgence in the interest to build new nuclear plants, the issue of nuclear waste is prevalent—even more so with the decision by the Obama Administration to abandon a permanent repository at Yucca Mountain, Nevada after over 20 years of research and billions of dollars of carefully planned and reviewed scientific field work. So we're here today to receive testimony from our four expert witnesses on the facts and on the pros and cons of reprocessing and recycling used nuclear fuel. I believe that finding some sort of a solution to how to handle our used nuclear fuel is critical to the continued successful contribution of nuclear energy to our country's electric generation and I look forward to hearing from today's witnesses on this important and timely topic.

Chairman GORDON. Thank you, Dr. Ehlers. I will point out that I think that we are the only Committee on the House side and maybe the Senate too in the last several years that has had any type of hearings on nuclear energy. We are going to continue with that. We have had a variety as well as roundtables. I think that you are absolutely correct, that we need to play a strong role in making sure that decisions are made on a scientific basis and not just an emotional basis, and I think we can play a good role there. You will also be pleased to know that the Administration has not abandoned the Yucca Mountain site but rather put it on hold, continuing their—they are continuing with all the various paperwork moving forward. They are putting it on hold while they have a council group that is going to make recommendations on that in the future. So hopefully—and Secretary Chu and Speaker Pelosi both spoke before this committee saying that it was part of the overall solution.

Now, if there are Members who wish to submit additional opening statements, your statements will be added to the record, and I think Mr. Rohrabacher would like to do that.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good Morning. Thank you, Mr. Chairman, for holding today's hearing to examine nuclear fuel recycling and to hear testimony on the research and development programs to address the challenges and opportunities of fuel recycling.

In order to develop a sustainable energy policy we must consider all available sources of energy that will reduce our dependence on foreign oil, improve our greenhouse gas emissions, and satisfy our energy needs. Nuclear energy is an integral part of this new energy plan. However, questions remain about the safety and security of using nuclear energy.

Currently, the U.S. uses nuclear energy to provide approximately 20 percent of electricity. However, we do not reprocess the spent fuel from these reactors, which accumulates at a rate of 2,000 metric tons per year. Our current nuclear waste laws only allow for the disposal of waste at the Yucca Mountain site, but the proposed Fiscal Year 2010 budget cut funding to Yucca Mountain by $100 million, further delaying the site's proposed 2020 opening. The time has come to consider new ways to dispose of and reprocess used nuclear fuels.

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, 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 to hear from our witnesses today how we can change and update our research and development program to ensure that we are using cutting-edge technology and providing appropriate levels of funding. In particular, I would like to know how we can ensure that our fuel reprocessing will not create a national security risk by isolating pure plutonium and how we can work through this committee and through Congress to ensure that these programs receive appropriate funding.

I welcome our panel of witnesses, and I look forward to their testimony. Thank you again, Mr. Chairman.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Good morning, Mr. Chairman. I am happy to see that the Committee is studying the issue of nuclear fuel reprocessing.

It is my belief that nuclear energy has an undeserved negative reputation.

The fact is that nearly any energy generation method comes with risks for personal and environmental harms.

Nuclear power has the capacity to generate a lot of electricity.

France utilizes it almost exclusively. Twenty percent of our nation's power comes from nuclear.

The House Committee on Science and Technology has held hearings in the past on this issue. The consensus from expert witnesses from the past has been that the storage of spent fuel is the most bedeviling issue.

In the past, witnesses have added that reprocessing can be done, but current methods expend more energy to accomplish the reprocessing to really make it worth the effort.

However, I am glad that this committee is willing to revisit the issue.

As you all know, Texas is the Nation's largest energy-producing state.

It is rich in natural resources such as natural gas, oil, wind, and solar.

Nearly 40 percent of Texas' electricity output relies on coal, and nearly all of that comes from mines that are owned by the utilities they supply.

The unfortunate news is that Texas ranks highest in the Nation in carbon dioxide emissions.

Greater diversification of its energy source mix could help Texas do better, when it comes to greenhouse gas emissions.

Texas ranks 7th among the 31 States with nuclear capacity. It is my understanding that nuclear energy produces relatively less pollutants per unit of energy generated.

I have mixed feelings about the continuing delays in finding a repository for nuclear waste. The “not in my backyard” argument is strong, and I can understand that sentiment.

Today’s hearing will be helpful to understand whether technology developments have made it more feasible to move toward nuclear power.

Although we as Members of Congress should not be in the business of picking winners and losers in the energy debate, I believe that it is important to study the issues and provide a broad base of federal support.

I thank the witness for appearing today and for providing testimony.

Thank you, Mr. Chairman and Ranking Member. I yield back the remainder of my time.

[The prepared statement of Mr. Davis follows:]

PREPARED STATEMENT OF REPRESENTATIVE LINCOLN DAVIS

Mr. Chairman and Ranking Member, I’d like to thank you both for holding today’s hearing to discuss nuclear waste recycling, a nuclear waste management strategy that includes utilizing recycled spent nuclear fuel, and how this strategy could support our nation’s goal of energy independence. My home State of Tennessee has long supported the technological expansion of America’s energy portfolio. From rural electrification under the Tennessee Valley Authority to the great investments being made in solar energy today, Tennessee has contributed significantly to America’s efforts. Biofuels, wind, coal, natural gas and other sources of energy will all have their part to play in America’s future, and the search for cleaner, more efficient alternative fuels is an admirable goal that we should continue to support, but we simply cannot meet our needs or fulfill our obligations without making nuclear energy a part of the mission.

Roughly thirty percent of the energy used to produce electricity in Tennessee comes from the six nuclear reactors in our area. This energy is and always has been emissions free, is delivered to rate payers at a fraction of the cost associated with coal, natural gas, or oil, and it has a far better safety record. We have a considerable stockpile of enriched, processed uranium that could and should go into commercial use by our energy sector, not to mention the amount of weapons-grade uranium that could be used as a nuclear power source. In this economy, with our energy independence at stake and a national commitment to cleaner, more efficient power on the line, we must make nuclear energy a part of our nation’s future.

The Babcock & Wilcox Company is currently working on a design for a new nuclear reactor that could be the practical, affordable, near-term answer we are looking for to meet our growing demand for clean, zero emissions, power generation. The Tennessee Valley Authority has shown interest in this project as an attractive energy solution for many nuclear operating companies.

Putting to use recycled nuclear fuel, when it is appropriate to do so, could prove to be a major player in an energy strategy that incorporates nuclear as a source. In order to realize fully the long-term benefits of nuclear energy, the United States and other nations need to develop these advanced fuel-cycle technologies. Additionally, we must remember that any decision to pursue advanced fuel cycles in the United States needs to consider economic and nonproliferation challenges associated with recycling uranium fuel.

I want to thank the witnesses for coming today, and I look forward to hearing your testimonies and what you see as the benefits and risks associated with this technology.

[The prepared statement of Mr. Mitchell follows:]

PREPARED STATEMENT OF REPRESENTATIVE HARRY E. MITCHELL

Thank you, Mr. Chairman.

Nuclear power provides a significant portion of our nation’s electricity supply. According to the Nuclear Regulatory Commission, there are commercial nuclear power reactors licensed to operate in 31 states. These reactors provide approximately 20 percent of our nation’s electricity supply.

Nuclear power is a critical electricity source in Arizona where we have the largest nuclear generation facility in the Nation, the Palo Verde Nuclear Generating Station.

However, as these nuclear power reactors continue to operate, spent nuclear fuel continues to accumulate without a clear strategy of how to store this waste.

Today we will explore the benefits and risks of nuclear waste recycling. We will also discuss the research development and demonstration needed to address the technical challenges and policy objectives of recycling spent nuclear fuel.

I look forward to hearing more from our witnesses on what advanced technologies may be developed to make nuclear waste recycling possible.

I yield back.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman, and first of all, let me commend you for this hearing and your fairness. If there is a—I have a letter that I have received from Nikolay Ponomarev-Stepnoy, who is a senior member, a Vice President of the Kurchatov Institute in Moscow, and he is a highly respected Russian physicist, and I would like if possible to submit this letter from him to the record but read a small portion of it as we begin.

Chairman GORDON. You know, it might be best to wait. Let us make—we will make the letter a part of the record if there is no objection, and with your opening statement——

Mr. ROHRABACHER. Opening statement or——

Chairman GORDON. Or when your question time—I think that might be a better——

Mr. ROHRABACHER. Yes, sir.

Chairman GORDON. If that is okay?

Mr. ROHRABACHER. That is a good idea.

Chairman GORDON. Thank you. Any other Members now or that aren't present here will have two weeks to submit an opening statement.

At this time I would like to introduce our panel of expert witnesses. Dr. Alan Hanson is the Executive Vice President for Technology and Used Fuel Management at Areva International, or Incorporated, rather. Ms. Lisa Price is the Senior Vice President of GE Hitachi Nuclear Energy and Chief Executive Officer of Global Nuclear Fuel. And Dr. Charles Ferguson is the Philip D. Reed Senior Fellow for Science and Technology at the Council for Foreign Relations. And I now yield to my colleague from Illinois, Ms. Biggert, to introduce a witness from her home state.

Ms. BIGGERT. Thank you, Chairman Gordon. I would like to welcome Dr. Mark Peters from Argonne National Laboratory as one of today's witnesses. I am very pleased that he could be here to enlighten the Committee on the important work done in my District on reprocessing research. Dr. Peters is currently the Deputy Associate Lab Director for the Energy Sciences and Engineering Directorate. He juggles the responsibility for management and integration of the lab's energy research and development portfolio and also provides technical support to the DOE's Advanced Fuel Cycle Initiative where he was recently appointed AFCI National Campaign Director for spent fuel disposition.

As most of you can see from his bio, Dr. Peters has extensive nuclear research and repository experience as a former Yucca Mountain project science and engineering manager at Los Alamos and at the DOE Office of Civilian Radioactive Waste, so I have had the pleasure of working with Dr. Peters over the years and know that his perspective will be very informative. So I look forward, Dr. Peters, to your testimony and appreciate you being here today. I yield back.

Chairman GORDON. Thank you, and Ms. Biggert, you will be glad to know that Chuck Atkins, our Chief of Staff, was there Monday, went through, had a tour of Argonne and was very impressed with the operation there.

The witnesses will have five minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When you have completed your spoken testimony, we will begin with questions. Each Member will then have five minutes, and we will begin with Dr. Mark Peters. Dr. Peters, you may begin.

## STATEMENT OF DR. MARK T. PETERS, DEPUTY ASSOCIATE LABORATORY DIRECTOR, ARGONNE NATIONAL LABORATORY

Dr. PETERS. Chairman Gordon, Dr. Ehlers, Mrs. Biggert and Members of the Committee, thank you for the opportunity to testify before you on advanced technology for nuclear fuel recycling. My name is Mark Peters and I am the Deputy Associate Lab Director for Energy Sciences and Engineering at the Argonne National Laboratory. Mr. Chairman, I ask that my full written testimony be entered into the record and I will summarize it here.

So I want to talk about—summarize my testimony going over three general areas. First, provide an introduction and some context and then a bit about spent nuclear fuel management and the fuel cycle, and then finally talk about the advanced nuclear fuel cycle research and development program and needs going forward.

So by way of introduction, world energy demand is increasing at a rapid pace. In order to satisfy the demand to protect the environment for future generations including reduction of greenhouse gas emissions, future energy sources must evolve from the current dominance of fossil fuels to a more balanced, sustainable approach to energy production that is based on abundant, clean and economical energy sources. Nuclear energy is already a reliable, abundant and carbon-free source of electricity in the United States and the world. In addition to contributing to future electricity production, it could also be a critical resource for fueling the transportation sector. However, nuclear energy must experience significant growth to achieve the goals of reliable, affordable energy in a carbon-constrained world.

There are a number of challenges associated with the global expansion of nuclear power. Any advanced nuclear fuel cycle aimed at meeting these challenges must simultaneously address issues of economics, uranium resource utilization, nuclear waste minimization and a strengthened nonproliferation regime, all of which require systems analysis and investment in new technologies.

In the end, the comprehensive and long-term vision for expanded sustainable nuclear energy must include safe and secure fuel cycle technologies, cost-effective technologies for the overall fuel cycle system, and ultimately a closed fuel cycle for waste and resources management. Related to spent nuclear fuel management, the nuclear fuel cycle is a cradle-to-grave framework that includes uranium mining, fuel fabrication, energy production and nuclear waste management.

There are two basic nuclear fuel cycle approaches. An open or once-through fuel cycle as currently planned by the United States involves treating spent nuclear fuel as waste with ultimate disposition of material in a geologic repository. In contrast, a closed or recycle fuel cycle, as currently planned by other countries, for example, France, Russia and Japan, involves treating spent nuclear fuel as a resource whereby separations and actinide recycling and reactors work with geologic disposal.

For reprocessing to be beneficial as opposed to counterproductive, it must be followed by recycling, transmutation and fission destruction of the ultra-long-lived radiotoxic constituents. Reprocessing by the so-called PUREX method, which is plutonium and uranium covered by extraction followed by plutonium recycling using mixed oxide fuel in light water reactors, is a well-established technology but is only a partial solution.

It is not at all clear that we should embark on this path, especially since the United States has not made a massive investment in a PUREX/MOX infrastructure, although the United States is proceeding with a plan to reduce its excess weapons plutonium inventory using MOX in LWRs. In contrast, advancement of fast reactor technology for transuranic recycling consumption would maximize the benefits of waste management and also allow essential progress toward the longer-term goal of sustainable use of uranium and subsequently thorium with fast reactors.

There is no urgent need to deploy recycling today, but as nuclear expands, a once-through fuel cycle will not be sustainable. To maximize the benefits of nuclear energy in an expanded nuclear energy future, it will ultimately be necessary to close the fuel cycle. Fortuitously, it is conceivable that the decades-long hiatus in the United States investment circumvents the need to rely on a dated recycling infrastructure. Rather, we have the option to develop and build new technologies and develop business models using advanced systems.

Related to the R&D program, to reduce cost, ensure sustainability and improve efficiency, safety and security, significant investments on the order of several hundred million dollars per year in a sustained nuclear energy R&D program are needed. Such a program must effectively support and integrate both basic and applied research and use modeling and simulation capabilities to address both near-long evolutionary activities, such as life extensions of the current nuclear fleet, and long-term solutions, for example, advanced reactors and fuel cycle technologies and facilities.

As the nuclear industry pursues evolutionary R&D to further improve efficiencies along each step of the current fuel cycle, it is incumbent upon the government to implement long-term, science-based R&D programs for developing transformational technologies and options for the advanced fuel cycle. In the very near-term we recommend that the United States' advanced fuel cycle program develop a science and technology roadmap. This would involve national labs, universities and industry and be a—start with a comprehensive set of options for fuel cycle technologies and overall systems. The roadmap should describe the technical readiness, risks and potential benefits of each option and the required R&D for each. This would be followed by implementation of a robust science-based R&D program to address all the challenges related to the fuel cycle.

Finally, there is sufficient time to analyze the technology options, choose the paths to investigate and conduct the science-based R&D and technology demonstrations that would be needed in the future for making decisions about the nuclear fuel cycle in the United States. However, it is imperative to begin now to build the R&D infrastructure that is needed for science and technology development, which must include advances in theory, modeling and simulation, new separation, fuel and waste management technologies, and advanced reactor concepts.

With that, I thank you and would be pleased to answer any questions.

[The prepared statement of Dr. Peters follows:]

PREPARED STATEMENT OF MARK T. PETERS

**Introduction and Context**

World energy demand is increasing at a rapid pace. In order to satisfy the demand and protect the environment for future generations, including reduction of greenhouse gas emissions, future energy sources must evolve from the current dominance of fossil fuels to a more balanced, sustainable approach to energy production that is based on abundant, clean, and economical energy sources. Therefore, there is a vital and urgent need to establish safe, clean, and secure energy sources for the future on a worldwide basis. Nuclear energy is already a reliable, abundant, and "carbon-free" source of electricity for the United States and the world. In addition to contributing to future electricity production, nuclear energy could also be a critical resource for "fueling" the transportation sector (e.g., electricity for plug-in hybrid and electric vehicles and process heat for hydrogen and synthetic fuels production) and for desalinating water. However, nuclear energy must experience significant growth to achieve the goals of reliable and affordable energy in a carbon-constrained world.

There are a number of challenges associated with the global expansion of nuclear power. Such a global expansion will create potential competition for uranium resources for fuel, the need for increased industrial capacity for construction, the need for integrated waste management, and the need to control proliferation risks associated with the expansion of sensitive nuclear technologies. Moreover, domestic expansion of nuclear energy will increase the need for effective nuclear waste management in the United States.

Any advanced nuclear fuel cycle aimed at meeting these challenges must simultaneously address issues of economics, uranium resource utilization, nuclear waste minimization, and a strengthened nonproliferation regime, all of which require systems analysis and investment in new technologies. In the end, a comprehensive and long-term vision for expanded, sustainable nuclear energy must include:

- Safe and secure fuel-cycle technologies;
- Cost-effective technologies for an overall fuel-cycle system; and
- Closed fuel cycle for waste and resource management.

**Spent Nuclear Fuel Management**

The nuclear fuel cycle is a cradle-to-grave framework that includes uranium mining, fuel fabrication, energy production, and nuclear waste management. There are two basic nuclear fuel-cycle approaches. An open (or once-through) fuel cycle, as currently planned by the United States, involves treating spent nuclear fuel as waste, with ultimate disposition of the material in a geologic repository (see Figure 1). In contrast, a closed (or recycle) fuel cycle, as currently planned by other countries (e.g., France, Russia, and Japan), involves treating spent nuclear fuel as a resource whereby separations and actinide recycling in reactors work with geologic disposal (see Figure 2).

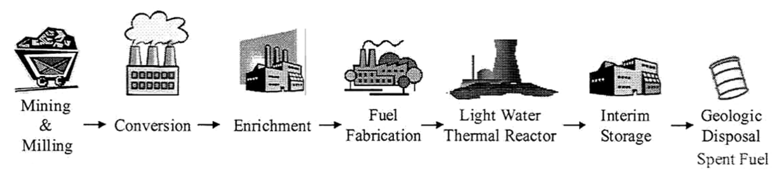


Figure 1. Open (or once-through) nuclear fuel cycle

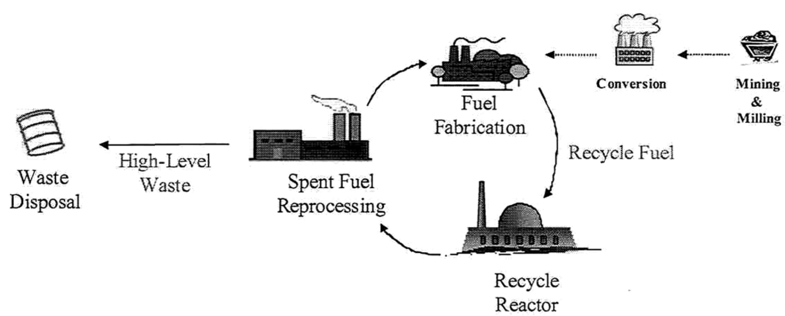


Figure 2. Closed nuclear fuel cycle (or reprocessing/recycling)

One of the key challenges associated with the choice of either option is spent nuclear fuel management. For example, current United States policy calls for the development of a geologic repository for the direct disposal of spent nuclear fuel. The decision to take this path was made decades ago, when the initial growth in nuclear energy had stopped, and the expectation was that the existing nuclear power plants would operate until reaching the end of their design lifetime, at which point, all of the plants would be decommissioned and no new reactors would be built. While it may be argued that direct disposal is adequate for such a scenario, the recent domestic and international proposals for significant nuclear energy expansion call for a reevaluation of this option for future spent fuel management (see Figure 3). While geologic repositories will be needed for any type of nuclear fuel cycle, the use of a repository would be quite different for closed fuel-cycle scenarios.

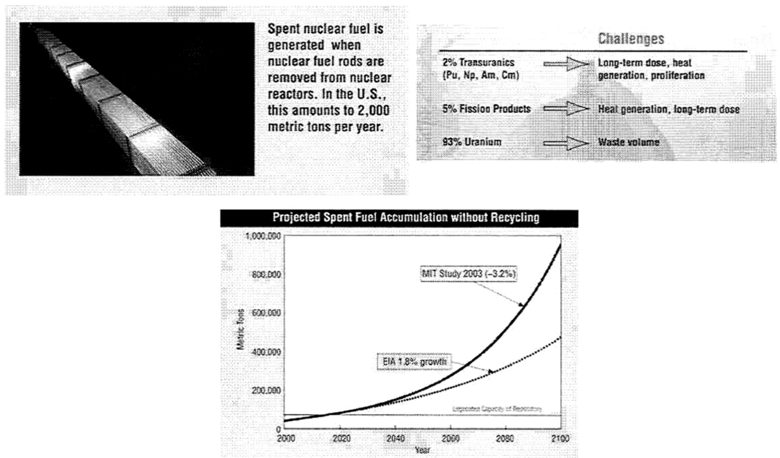


Figure 3. Spent nuclear fuel generation and management

For reprocessing to be beneficial (as opposed to counterproductive), it must be followed by recycling, transmutation, and fission destruction of the ultra-long-lived radiotoxic constituents (for example, plutonium [Pu], neptunium [Np], americium [Am]; the Pu-241 to Am-241 to Np-237 chain is the dominant one). Reprocessing (with Plutonium and Uranium Recovery by Extraction [PUREX]) followed by Pu mono-recycling (mixedoxide [MOX] fuel in light water reactors [LWRs]) is well established, but is only a partial solution. It is not at all clear that we should embark on this path, especially since the United States has not made a massive investment in a PUREX/MOX infrastructure. (Although, the United States is proceeding with a plan to reduce excess-weapons Pu inventory using MOX in LWRs.) In contrast, advancement of fast reactor technology for transuranic [TRU] recycling and consumption would maximize the benefits of waste management and also allow essential progress toward the longer-term goal of sustainable use of uranium (and subsequently thorium) with fast reactors.

There is no urgent need to deploy recycling today, but as nuclear energy expands, a once-through fuel cycle will not be sustainable. To maximize the benefits of nuclear energy in an expanding nuclear energy future, it will ultimately be necessary to close the fuel cycle. Fortuitously, it is conceivable that the decades-long hiatus in United States investment circumvents the need to rely on a dated recycling infrastructure. Rather, we have the option to develop and build new technologies and develop business models using advanced systems.

**Advanced Fuel-Cycle R&D Program**

To reduce cost, ensure sustainability, and improve efficiency, safety, and security, significant investments (several hundred million dollars per year) in a sustained nuclear energy research and development (R&D) program are needed. Such a program must effectively support and integrate both basic and applied research and use modeling and simulation capabilities to address both near-term evolutionary activities (e.g., life extensions of the current nuclear fleet) and long-term solutions (e.g., advanced reactors and fuel-cycle technologies and facilities). As the nuclear industry pursues evolutionary R&D to further improve efficiencies along each step of the current fuel cycle, it is incumbent upon the government to implement long-term, science-based R&D programs for developing transformational technologies and options for advanced nuclear fuel cycles. Including nuclear regulators in the research and evaluation of results will facilitate the licensing and regulation of future nuclear facilities and technologies.

The growth of the scientific basis for nuclear energy and its translation into design concepts and technology advances will enable expanded, sustainable use of nuclear energy to meet energy needs worldwide in a safe, secure, and cost-effective manner through:

- Discovery and understanding of relevant phenomena;
- Creation of innovative concepts;
- Science-based approaches involving theory, experimentation, and modeling and simulation followed by demonstrations of new technologies; and
- Optimization of future nuclear energy systems in the context of technological, environmental, nonproliferation, security, and socioeconomic factors.

Planning the R&D required to support future implementation requires consideration of not only domestic nuclear energy development needs, but also an understanding of the global context in which nuclear energy will continue to grow. This requires a forward-looking program to conduct R&D defined by consideration of a broad range of planning assumptions for future nuclear energy use and effective approaches for improving waste management, nuclear nonproliferation, resource utilization, and economics. In summary, an advanced fuel-cycle R&D program, including fundamental R&D and technology development, is needed to examine a range of possibilities to determine the most important aspects, identify what the risks may be, and define what steps may be needed to successfully leapfrog existing technologies.

An essential part of the overall program supporting nuclear energy is the fundamental R&D that addresses long-range development issues. These include:

- Timelines for potential nuclear energy deployment strategies to identify possible nuclear energy infrastructures, both global and domestic, and the science and technology development needs and timing of availability;
- Understanding the current technical status (including industry, the national laboratory complex, and universities) and planning for a reasoned development;
- Fundamental development of key technologies to resolve existing or anticipated issues related to waste management, nonproliferation, resource utilization, and economics; and
- Identify the need for research and development facilities, including utilization of existing infrastructure, for development and testing of the key technologies, including determining the deployment times for these facilities.

In the very near-term, we recommend that the United States advanced fuel-cycle program develop a *Science and Technology Development Roadmap.* Based on a comprehensive set of options for fuel-cycle technologies and overall systems, the roadmap should describe the technical readiness, risks, and potential benefits of each option and the required R&D plan for each. This should be followed by implementation of a robust, science-based R&D program involving advanced reactors, separations, transmutation fuel, and waste management to enable timely identification of the technology options for a sustainable closed fuel cycle, identify what the risks may be, and define what steps are needed to successfully leapfrog existing recycling technologies.

In the long-term, the required basic and applied R&D includes:

- Science and discovery contributions to technology/design;
- Increased role of modeling and simulation in nuclear energy R&D and design of nuclear energy systems;
- Improved systems analysis of nuclear energy deployment strategies;
- Advances in separations and fuel technologies to close the fuel cycle, e.g.,
  - — Develop and demonstrate aqueous-based technologies;
  - — Develop and demonstrate pyroprocessing technologies; and
  - — Develop and demonstrate transmutation fuels.
- Advances in nuclear reactor technology and design to generate electricity and close the fuel cycle, e.g.,
  - — Develop advanced reactor concepts;
  - — Develop advanced reactor component testing facilities; and
  - — Develop a demonstration fast reactor.
- Advancement of safe and secure use of nuclear energy on an international basis, e.g.,
  - — Enhance safety assurance capabilities in countries newly adopting nuclear power; and
  - — Improve safeguard technologies and practices.

- Education and training of future nuclear energy professionals; and
- University programs and partnering with institutions that have nuclear energy programs.

Finally, there is sufficient time to analyze the technology options, choose the paths to investigate, and conduct the science-based R&D and technology demonstrations that would be needed in the future for making decisions about the nuclear fuel-cycle infrastructure in the United States. However, it is imperative to begin now to build the R&D infrastructure that is needed for science and technology development, which must include advances in theory; modeling and simulation; new separations, fuel, and waste management technologies; and advanced reactor concepts.

BIOGRAPHY FOR MARK T. PETERS

Dr. Mark Peters is the Deputy Associate Laboratory Director for the Energy Sciences and Engineering Directorate at Argonne National Laboratory (ANL). Responsibilities of his position include the management and integration of the Laboratory's energy R&D portfolio coupled with development of new program opportunities at the Laboratory, and management of the energy-related Laboratory Directed Research and Development program (LDRD). Dr. Peters also provides technical support to the DOE Advanced Fuel Cycle Initiative (AFCI) and was recently appointed AFCI National Campaign Director for Spent Fuel Disposition.

Selected to serve on a two-year detail to DOE Headquarters in Washington, D.C., Dr. Peters worked as a senior technical advisor to the Director of the Office of Civilian Radioactive Waste Management. In a prior position, Dr. Peters was with Los Alamos National Laboratory, where he served as the Yucca Mountain Project (YMP) Science and Engineering Testing Project Manager. In that role, he was responsible for the technical management and integration of science and engineering testing in the laboratory and field on the YMP.

Before joining Los Alamos National Laboratory and the YMP in 1995, Dr. Peters had a research fellowship in geochemistry at the California Institute of Technology where his research focused on trace-element geochemistry. He has authored over 60 scientific publications, and has presented his findings at national and international meetings. Dr. Peters is a member of several professional organizations including the Geological Society of America, where he served as a member of the Committee on Geology and Public Policy. In addition, he is a member of the American Geophysical Union, the Geochemical Society, the Mineralogical Society of America, and the American Nuclear Society. Dr. Peters' professional achievements have resulted in his election to Sigma Xi, the Scientific Research Society, as well as Sigma Gamma Epsilon, the Earth Sciences Honorary Society.

Dr. Peters received his Ph.D. in Geophysical Sciences from the University of Chicago and his B.S. in Geology from Auburn University.

Chairman GORDON. Thank you, Dr. Peters.

Dr. Hanson, you are recognized.

**STATEMENT OF DR. ALAN S. HANSON, EXECUTIVE VICE PRESIDENT, TECHNOLOGY AND USED FUEL MANAGEMENT, AREVA NC INC.**

Dr. HANSON. Thank you, Mr. Chairman and Members of the Committee. My name is Alan Hanson. I am an Executive Vice President at Areva. On behalf of Areva's 6,000 U.S. employees, I appreciate this opportunity to testify before you today. Relevant to today's testimony is the fact that Areva operates the largest and most successful recycling facilities in the world. I am going to focus first on some of the benefits and criticisms associated with recycling.

The main benefits I think are reasonably well known. There is a conservation of uranium resources that occurs because of the recovery of material and its reuse. Recycling makes waste management easier by reducing the volumes, the heat loads and changing the waste form which is to be disposed of, and importantly, recycling is a path to burning plutonium and removing it from proliferation concern. Recycling as we perform it today destroys about 30 percent of the plutonium and it alters the composition of the uranium and plutonium so that it is no longer very attractive for weapons purposes.

Now, in contrast to these benefits, the criticisms are in three areas, first, nonproliferation, then cost, then the volume of waste. I want to focus on this nonproliferation issue because this is the reason we are not doing reprocessing in the United States today. In recent years many countries have embarked on a nuclear weapons program for reasons of national prestige and power but they have not done it using the commercial fuel cycle. They have done it in a dedicated program. The vast majority of countries seek only peaceful uses of nuclear power and they rely upon the industry to provide them with enriched material and recycling services rather than build their own facilities. This is one way to control the spread of the nuclear facilities, by having a robust industry providing services. A fundamental question is, would a decision by the United States to recycle and close the fuel cycle, would this contribute to proliferation or would it do the opposite and contribute to nonproliferation? I have a strong belief that it would do the latter, that it would contribute to nonproliferation.

Let us examine the case for proliferation, and I will start with diversion. The United States has for a long time had a plutonium economy in the military complex. They have demonstrated a wonderful ability to control the material and to keep it from diversion. There is no reason in my mind that the same techniques that are used for our weapons program cannot be used for commercial recycling to make sure that there is not a diversion. What about theft? The same argument holds true. We have not had thefts of sensitive nuclear material in the United States. It is very well protected, and I don't see any reason again that we can't protect commercial material in the same way. This leaves only one reason to forego recycling, and that is the issue of setting an example for the rest of the world. This is the ostensible reason that we are not recycling. But that policy has not stopped France, the U.K., Russia and Japan from doing recycling and it will not stop China and India from doing it. Those are the next two nations which are going to embark on recycling programs. I would strongly recommend, as an individual and as a representative of Areva, that the United States step to the forefront and build a recycling complex which can provide a service to other countries to make it unnecessary and uneconomical for them to pursue their own recycling, and this would be a step forward on nonproliferation.

I am not going to spend a lot of time on cost. This can be an expensive proposition. It can be done in an economical fashion as we are doing in Europe. The cost of the fuel cycle for nuclear power is such a small fraction of the total cost of electricity produced that if we were to double the costs of handling the back end of the fuel cycle, the consumer would see a few pennies a month, so it is not economically unattractive.

On waste, the volume reduction is enormous. It is at least a factor of four for the repository for the high-level materials. You do end up with a little bit more of the low-level materials which need to go into surface burial, but our calculations show that this would increase low-level waste only by about two and a half percent, which is certainly not an onerous price to pay.

With regard to R&D, we are very supportive of R&D in the federal complex. There are things that industry will not do because they are too long-term or too speculative. We are very supportive of the AFCI initiative which Mark Peters referred to. We believe this should go forward, that work should continue to be done on advanced aqueous separations and also on electro-metallurgical separations, which are not as advanced as aqueous processing, and I think that Lisa Price will have more to say about that. We should not be seeking a proliferation-proof fuel cycle. It doesn't exist. We can't find it. We can make it proliferation resistant and that is what we need to do.

I would end my testimony here by trying to answer very quickly your question. I would personally vote for proceeding in a rather determined and in a near-term basis to implement recycling in the United States. I think waiting for Generation IV technologies would be another mistake for this country. Thank you very much.

[The prepared statement of Dr. Hanson follows:]

PREPARED STATEMENT OF ALAN S. HANSON

Mr. Chairman and Members of the Committee:

My name is Alan Hanson, and I am Executive Vice President, Technology and Used Fuel Management, of AREVA NC Inc.

I appreciate this opportunity to testify before you today on advanced technology for nuclear fuel recycling.

AREVA Inc. is an American corporation headquartered in Maryland with more than 6,000 employees in over 40 locations across 20 U.S. states. Last year, our U.S. operations generated revenues of $2.5 billion—12 percent of which was derived from U.S. exports. We are part of a global family of AREVA companies with 75,000 employees worldwide offering proven energy solutions for emissions-free power generation and electricity transmission and distribution. We are proud to be the leading supplier of products and services to the worldwide nuclear industry, and we are the only company in the world to operate in all aspects of the nuclear fuel cycle.

AREVA designs, engineers and builds the newest generation of commercial nuclear plants and provides reactor services, replacement components and fuel to the world's nuclear utilities. We offer our expertise to help meet America's environmental management needs and have been a longtime partner with the U.S. Department of Energy on numerous important projects. Relevant to today's testimony is the fact that AREVA operates the largest and most successful used fuel treatment and recycling plants in the world.

As I read the Committee invitation, you have requested information in five subject areas:

(1) Explore the risks and benefits associated with the recycling of used nuclear fuel;

(2) Discuss the research, development and demonstration needs at the federal level as the U.S. reviews its nuclear waste management strategy;

(3) Describe AREVA's strategy for management of used nuclear fuel, including the technologies deployed for establishing a closed fuel cycle;

(4) Discuss the environmental impacts of recycling and the safety measures AREVA has adopted to address concerns about nuclear proliferation; and

(5) Recommend any research, development and demonstration needs that could make nuclear waste recycling safer, more efficient and/or cost effective.

What I hope to accomplish today is to address each of these requests in the testimony that follows.

**Benefits and Criticisms Associated With Recycling**

The main benefits associated with the recycling of used nuclear fuel can be summarized as follows:

- Recycling makes waste management easier.
- Recycling provides strategic flexibility and confidence for the long-term.
- Recycling saves natural resources.
- Recycling is a path to burning plutonium, thereby reducing proliferation concerns.

**Recycling makes waste management easier.** Recycling used nuclear fuel reduces the volume of high-level waste to be disposed of in a final repository.

Only four percent of used fuel content is high-level waste. When such waste is *vitrified,* or specially-packed into a highly compact glass-like waste form for final storage, and added to the volume of compacted structural waste and high-level process waste, the total volume necessary for final disposal is 75 percent less than the volume required if the used fuel is disposed directly in a repository.

The volume required in the repository is further reduced if the vitrified waste is allowed to "cool" in interim storage for some decades before actual emplacement in a repository. This is due to the thermal load issue. For example, if vitrified waste is stored for 70 years of cooling before emplacement, the volume reduction factor would double. And volume requirements could be even further reduced when future technologies such as transmutation are available for deployment.

High-level waste volume reduction is a crucial benefit of recycling as it allows maximum use of a geological repository, a rare and precious asset. When a high-level waste repository eventually opens in the U.S., one would want to make optimal use of every cubic unit of emplacement. Licensing of such a facility is long, and public acceptance is very sensitive. It is difficult to envisage today an attempt to license multiple geological repositories in the U.S. It is already difficult enough just to license the first one.

It is worth noticing that today the quantity of used fuel already discharged from U.S. reactors is very significant, approximately 60,000 metric tons. If Yucca Mountain were to open in the next decade, the amount of fuel available for emplacement would already completely fill the repository's legal capacity, leaving no place to dispose newly-generated waste. Furthermore, about 2,000 metric tons of used fuel is discharged every year by the U.S. commercial nuclear reactor fleet of 104 reactors. Even if no more reactors were to be built in the U.S., an additional 20,000 metric tons of used fuel would accumulate every decade the U.S. waits.

The main contributor to the long-term radioactive toxicity of used nuclear fuel is plutonium for the first several hundreds of thousands of years, then minor actinides and uranium become predominant. Consequently, extracting plutonium and uranium from the waste for final disposal significantly reduces the waste's toxicity, by a factor of about 90 percent.

Recycling provides a highly safe, resistant and well-characterized waste form. Vitrified waste is a very robust matrix against dissolution by water, as strong as volcanic rock. It has been proven scientifically that after 100,000 years only one percent of its mass would be lost by leaching in water, and it would require more than 10 million years to completely dissolve in water. It is important to recognize that after 10,000 years, the radioactivity of a vitrified waste package is reduced down to that of natural uranium ore due to the natural decay of the radioactive atoms contained therein. Such robust characteristics of the waste form facilitate the long-term safety demonstration of the repository and consequently simplify the licensing process.

**Recycling provides strategic flexibility and confidence for the long-term.** Vitrified waste packages are no longer subject to International Atomic Energy Agency safeguards, as almost all of the fissile material, uranium and plutonium, has been removed to manufacture recycled fuel. Consequently waste from recycling can be safely and cost-effectively interim-stored in simple, compact and low-cost facilities.

Recycling provides a credible and reliable nuclear waste management option consisting of storing the vitrified waste for an extended period of time waiting for a geological repository to be ready and approved. Long-term interim storage of waste from recycling is easier and safer than interim storage of used fuel without recycling. Vitrified waste from 40 years of operation of the French nuclear reactor fleet, currently 54 power reactors, resides in a single building with a footprint that is less than two American football fields.

**Recycling saves natural resources.** Uranium recovered from recycling, also known as "RepU," represents about 95 percent of the mass of light water reactor used fuel with a residual $U^{235}$ enrichment level of 0.8 percent to 0.9 percent, higher than natural uranium ore.

Re-enrichment and recycling of RepU is performed by several utilities throughout the world. With the current and forecasted costs of nuclear fuel sourced from natural uranium, RepU becomes a secondary source that is quite attractive. Today, customers are asking AREVA to provide them with 100 percent recycling of their RepU. AREVA is making investments to ensure 100 percent RepU re-enrichment and RepU fuel fabrication by 2015.

Recycling RepU allows savings of 15 percent of natural uranium resources. Recycling plutonium into *mixed oxide,* or MOX, fuel allows about 12 percent of natural uranium savings. Recycling both recovered uranium and plutonium leads to a total savings of at least 27 percent of natural uranium resources.

The amount of U.S. commercial used nuclear fuel accumulated by 2010, 60,000 metric tons, if recycled represents the energy equivalent of eight years of nuclear fuel supply for today's entire U.S. nuclear reactor fleet. Energy recovery potential is, therefore, significant and enhances energy security.

**Recycling is a path to burning plutonium, thereby reducing proliferation concerns.** Recycling plutonium in MOX fuel consumes roughly one-third of the plutonium through single recycling and significantly alters the isotopic composition of the remaining plutonium, thus severely degrading its potential weapons attractiveness.

Burning plutonium in MOX fuel is the path that has been selected by the National Nuclear Security Administration to dispose U.S. weapons-grade plutonium declared in excess. With the assistance of AREVA, a MOX fuel fabrication facility is currently being constructed at the DOE Savannah River Site in South Carolina, and it is on track to start production of the first MOX fuel by 2016.

In contrast to the benefits described above, the criticisms of spent fuel recycling focus mainly on the following points:

- Non-proliferation
- Cost
- Volume of waste generated

**Non-proliferation.** In recent years, a few countries have sought to acquire nuclear weapons for reasons of national security, national power or national prestige. Their basic motivations were political. It is very important to note such countries never intended to use nuclear technology to produce a single kilowatt-hour of electricity. Meanwhile, the vast majority of countries in the world continue to seek ways to produce electricity on an efficient, competitive, sustainable, peaceful and responsible basis. They have no interest in developing or accessing sensitive nuclear technologies when it does not make economic sense for them and as long as security of supply is guaranteed for them.

There are ways and means to control the spread of material and technologies, mainly through the limitation of the number of facilities in the world and providing strong guarantees of supply to dissuade most countries from developing their own uranium enrichment or reprocessing capabilities.

There is a fundamental question of policy which should be important to this committee:

> Would a decision by the U.S. to recycle its used fuel and close the nuclear fuel cycle contribute to proliferation, or would it do the opposite and contribute to nonproliferation?

Let us examine the case for proliferation by diversion. Today we do not know if recycling in the U.S. would be carried out by a government entity or a commercial firm. If by a government entity, the diversion scenario is not relevant since the Federal Government already has a stockpile of weapons-grade plutonium and, therefore, has no use for less-effective reactor-grade plutonium. Since the U.S. Government has demonstrated an ability to prevent diversion of its weapons material, there is no reason to believe it could not prevent diversion of material recovered from used fuel by the same means. If recycling is done by a commercial entity, the government could impose its own safeguards in addition to IAEA safeguards to prevent diversion.

What about theft of weapons-usable material? The same logic applies as for diversion. The Federal Government has been successful at protecting its own stockpile of weapons-grade material, so there is no reason to believe that it cannot adequately protect less attractive reactor-grade materials.

If diversion or theft of plutonium can be prevented by extensive national and international safeguards and physical protection, then there remains only one reason for the U.S. to forego recycling and that is to avoid setting an example that might be followed by the rest of the world. This is the ostensible reason why the U.S. turned its back on recycling three decades ago. But that U.S. policy did not prevent Britain, France, Japan or Russia from building domestic recycling facilities, nor will it prevent China from following suit.

Notice that the only countries to build such facilities are those with a sizable amount of used fuel that makes it economically justifiable to do so. Other countries which chose to recycle elected to purchase the service rather than build their own facilities. This is similar to the model for enrichment espoused by U.S. policy, i.e., there is sufficient capacity and robust supply assurances that can make proliferation of expensive enrichment facilities unattractive. I would argue that the same logic can be applied to recycling and that a U.S. decision to offer such a service could prevent many countries from building indigenous facilities, thereby enhancing the nonproliferation regime.

**Cost.** In 2006, The Boston Consulting Group (BCG) performed a study with input from AREVA that showed that the economics of recycling as compared to direct disposal are comparable, within 10 percent difference. The reasons are the following:

- The cost of uranium has significantly increased in the past years, which increases the value of recycled fuel.
- The projected total life cycle cost of a geological repository is high, which provides high value for each cubic unit of emplacement saved due to recycling.
- A large recycling facility, about 2,500 metric tons per year capacity, provides significant cost savings through economies of scale.

Today, the conclusions of the BCG report are even truer as the long-term forecast for uranium cost is going up and the cost of the Yucca Mountain repository has also significantly increased.

Of course, any study depends upon the assumptions made, and other studies using different assumptions have produced results different from those of BCG. Of note, however, is a respectable study by the Congressional Budget Office (CBO) which concluded that costs for recycling would be somewhat higher then projected by BCG. However, the cost for management of the back-end of the fuel cycle is such a small part of the total cost of electricity produced that nuclear power would remain competitive even using the CBO estimates. The impact of recycling on the cost of electricity is between 0.1 and 0.2 cents per kilowatt-hour when the production cost of nuclear electricity is around two cents per kilowatt-hour.

**Volume of waste generated.** Recycling used fuel generates two types of waste streams classified according to their ultimate disposal pathway: surface disposal and underground, or geologic, disposal, the latter being orders of magnitude more complex, more expensive and more sensitive to implement as the focus of public acceptance issues is concerned. When comparing solid waste figures between the option to directly dispose used fuel or to recycle it, it is therefore fundamental to distinguish between those two types of waste.

As pointed out previously, the volume of material destined for the high-level waste repository is reduced by at least 75 percent through recycling. Some critics of recycling point out that there is a price to be paid for recycling which is an increased volume of low-level waste destined for near-surface disposal. Based on AREVA's experience, the projected increase in low-level waste to be disposed in near-surface facilities were the U.S. to recycle would approximate only 2.5 percent of the volume of such waste that is disposed annually in the U.S.

### Federal Research, Development and Demonstration

While industry can be relied on to carry out research and development on topics that are of near-term commercial interest, it is unrealistic to expect any industry to expend research funds on basic science or on topics with a very uncertain or a long-term payoff. It is these latter types of research which must be primarily a federal priority.

To its credit, the U.S. Department of Energy has for years devoted resources to the Advanced Fuel Cycle Initiative (AFCI). Such research should continue, but it should not focus solely on unattainable goals.

AFCI has often seemed to be a search for the non-existent "proliferation-proof" fuel cycle. It is important to understand that the laws of chemistry and physics preclude the existence of such a utopian fuel cycle. Any technology that allows the separation and/or the concentration of fissionable atoms has the potential for misuse. That is why the sensitive fuel cycle activities associated with enrichment and recycling must be adequately safeguarded and physically protected.

Even the search for a so-called "proliferation-resistant" fuel cycle may be a fruitless effort. To date, it appears that there is not a great deal of difference in proliferation resistance between any of the conceivable, realistic fuel cycles. An undue focus on self-protecting fuel forms could well lead to a nuclear fuel type which does not meet necessary standards for safety and economic efficiency. In this case, we should not expect to find a technological solution, a proliferation-resistant fuel cycle, for an inherently political problem, the proliferation of nuclear weapons. This problem demands political solutions, and technology should focus on giving political leaders the tools to accomplish their objectives, primarily enhanced safeguards systems and physical protection measures.

**AREVA's Used Fuel Management Strategy**

When nuclear fuel is discharged from a commercial reactor, it is actually not "spent." There is still a significant amount of fissile material remaining in used fuel—we call it *used* fuel instead of spent fuel for this very reason—still capable of providing at least 25 percent more energy. But this energy cannot be delivered in the conventional nuclear reactor because the fuel is progressively accumulating fission products; it is polluted by the "ashes" resulting from the fission reaction. Many byproducts of the fission of uranium atoms are neutron absorbers. And such absorptions reduce the population of neutrons available to induce new fission reactions. Then the fission reaction can no longer be sustained appropriately or cost-effectively.

This is when recycling comes into play. Recycling consists of separating the "ashes" from the reusable material, recovering the valuable material, uranium and plutonium, and manufacturing fresh new fuel out of it.

In terms of mass, 95 percent of used fuel contents is composed of reusable uranium, one percent is reusable plutonium, and the remaining four percent is actual waste which contains practically no remaining fissile material nor any energy value for the current and near-future generation of reactors. Recovered uranium is re-enriched and used to fabricate fresh new fuel, where the fissile material is $U^{235}$. Recovered plutonium is blended with depleted uranium to fabricate MOX, or mixed oxide, fuel, where the fissile materials are $Pu^{239}$ and $Pu^{241}$.

The four percent of actual waste is then specially packed through vitrification in order to provide a safe waste form with a very long-term stability. The vitrified waste is the package that is bound for disposal in a geological repository, together with the metallic structures of the fuel bundle.

AREVA today uses an aqueous process to recover the uranium and plutonium. It is an updated version of the PUREX process invented in the U.S. Future AREVA facilities will benefit from lessons learned and continuous improvement of our technology. The main features of new plants would be:

- Implementation of the new enhanced COEX™ process where no pure plutonium is separated anywhere in the facility, as a replacement for today's PUREX process.
- Co-location of treatment and fuel fabrication plants to avoid transportation of intermediate nuclear material outside of the facilities.
- Overall enhanced safeguards systems and "safeguards by design" approaches.

This is what is available and possible today and in the near to medium future. Current research is focusing on future processes capable to further extract material from the "ashes" that could be burned in a new generation of fast neutron spectrum reactors. In such next generation, Generation IV reactors, more atoms and more isotopes become fissionable because the fast neutrons produced are of much higher energy. Moreover, the long-lived actinides, which heavily drive the requirements for confinement in geological disposal, could be broken into shorter live atoms which, in theory, could lead to a dramatic reduction of the volume required to dispose remaining waste in a geological repository.

This is a very long-term story, probably 50 to 60 years before the first commercial operation. Of course, one could choose to wait for Generation IV recycling technologies, but the price to be paid for waiting is an enormous increase in world inventories of plutonium in used fuel and an enormous waste of energy potential if the used fuel is irretrievably disposed. It is also contrary to sustainable development principles under which we promise our children not to burden them with the legacy of our consumption.

**Environmental Impacts and Nuclear Security**

Protection of workers and of the environment is at the highest of AREVA's priorities. The environmental impact of our La Hague treatment operations remains below the natural background radiation level. The maximum potential impact on the most highly-exposed sectors of the public remains 100 times less than the natural radioactivity level. The natural background exposure at La Hague is about 2.4 millisieverts per year. The highest local exposure to farmers or fishermen is less than 0.02 millisieverts per year, which is equivalent to the exposure received by a passenger during one New York to Paris trans-Atlantic flight.

AREVA La Hague performs systematic and in-depth monitoring of the environment in the air, on land (e.g., surface water, grass and milk) and at sea (e.g., coastal waters, fish and seaweed) around the site. A host of measurements are taken; around 23,000 samples are taken every year, and 70,000 analyses are made every year under the scrutiny of independent authorities who also perform their own sampling and analyses.

AREVA takes very seriously its responsibility to minimize the risk of proliferation of sensitive nuclear facilities and materials. We believe that the spread of recycling and uranium enrichment technologies should be limited. At the recent Carnegie Endowment for International Peace meeting held in Washington, AREVA Chief Executive Officer Anne Lauvergeon stated emphatically that at this time there are only two countries to which AREVA would export its recycling technologies: the U.S. and China.

Strong guarantees of supply should dissuade the vast majority of countries from developing their own capabilities for recycling and enrichment. Industry support and a commercial model ensuring competition, profitability and reliability are necessary in this regard. Existence of a few competitors will provide the guarantee of continuous supplies at reasonable prices. Large-scale profitable facilities and industries are therefore an important asset. Long-term contracts can ensure credibility and sustainability of commitments.

France has developed a model under which it can accept used fuel to recycle in its domestic facilities, burn recovered plutonium in its reactors and return the waste to the country where the fuel was used to produce energy. Other countries may choose to retain the high-level waste and dispose of it along with their domestic waste in the future. In either case, there is no proliferation threat from the vitrified products of recycling.

New recycling plants in the world should incorporate enhanced nonproliferation and security features such as the COEX™ process with no pure separated plutonium, co-location of treatment and fuel fabrication plants to avoid intermediate nuclear material transportation, and robust safeguards systems and "safeguards by design" approaches.

**The Future of Safe and Efficient Recycling**

While AREVA takes pride in the successful operation of its recycling complex centered at the La Hague and MELOX facilities, we are convinced that further improvements can be made. In fact, continuous improvements have been made in France over the previous three decades based on research and development. Much of what has been learned was incorporated into the design of the Japanese recycling treatment plant at Rokkasho-mura. Future plants wherever they are located should take advantage of the advanced safeguards procedures built into the Rokkasho-mura facility and should also implement advanced technology such as COEX™, which does not separate pure plutonium.

In addition, AREVA believes that there are other areas for research, development and demonstration. Off-site doses are highly dependent on specific locations, as are the allowable levels of gaseous and liquid discharges. Research, development and demonstration should be concentrated on reducing the minimal gaseous and liquid discharges that arise from current processing technologies. The capture, packaging and disposal of gases and liquids are areas ripe for research. At the same time, such research should focus on the cost-benefit analysis of limiting discharges while assuring that worker dose rates are not inappropriately increased.

In the long-term, and especially in conjunction with the future implementation of Generation IV reactor technologies, electro-metallurgical separations may become a useful technology. Such separations technology has not yet reached the level of maturity found today with aqueous processing. This is another area suitable for research at the U.S. national laboratories because of the long-term time horizon for widespread commercial implementation.

Finally, further federal research, development and demonstration should be devoted to advanced safeguards technologies such as advanced instrumentation that will allow near-real time material accountancy. The development of that technology would contribute significantly to enhancing the assurance that sensitive materials are not being diverted.

Mr. Chairman and Members of the Committee, I appreciate having this opportunity to join you today. I am delighted that our lawmakers have taken an interest in advanced technology for nuclear fuel recycling. A used fuel recycling facility should be built in the U.S. in the near future in order not to postpone the waste management issue once again and for America to regain global leadership.

A nuclear renaissance is undeniably happening around the world. Britain, France, China, Japan and Russia have already built or are developing recycling capabilities. America was the first to develop this technology, we were the first to send a man to the Moon, and it is time for America to take the lead again. AREVA would be pleased to cooperate with the U.S. Department of Energy to further research, development and demonstration on recycling.

BIOGRAPHY FOR ALAN S. HANSON

Alan Hanson was appointed Executive Vice President, Technology and Used Fuel Management, of AREVA NC Inc. in 2005. He was formerly President and Chief Executive Officer of AREVA subsidiary Transnuclear, Inc., which he first joined in 1985. He continues his responsibilities there as a Director of the company.

Dr. Hanson began his career in 1975 with the Nuclear Services Division of Yankee Atomic Electric Company. In 1979, he joined the International Atomic Energy Agency in Vienna, Austria, where he served first as Coordinator of the International Spent Fuel Management Program and later as Policy Analyst with responsibilities for safeguards and nonproliferation policies.

Dr. Hanson completed his undergraduate studies in mechanical engineering at Stanford University and earned a Ph.D. in nuclear engineering from the Massachusetts Institute of Technology. He is a member of the American Nuclear Society and the American Society of Mechanical Engineers.

Chairman GORDON. Thank you, Dr. Hanson.

And now Ms. Price, you are recognized for five minutes.

**STATEMENT OF MS. LISA M. PRICE, SENIOR VICE PRESIDENT, GE HITACHI NUCLEAR ENERGY AMERICAS LLC; CHIEF EXECUTIVE OFFICER, GLOBAL NUCLEAR FUEL, LLC**

Ms. PRICE. Mr. Chairman, Dr. Ehlers and Members of the Committee, I appreciate the opportunity to speak with you today on a suggested approach for research, development and demonstration for nuclear fuel recycling.

GE Hitachi Nuclear Energy developed this approach based on technology originally funded by the Department of Energy. The options for dealing with the nuclear waste problem can really be categorized in three ways, in the three Rs: repository, reprocess or recycle. However, the differences between those three Rs drive the way you think about the opportunities and how to proceed. Long-term storage would be required in any of these scenarios. However, the amount of time that waste would have to be isolated in a repository depends on which R is selected. Now, why is that? It is because the most significant factor impacting long-term storage is the amount of heat that is generated principally by four elements in the used nuclear fuel called transuranics. The three Rs differ in how these transuranics are handled. So let us look at the three Rs briefly.

Repository refers to sequestering the used nuclear fuel in a permanent repository. A typical spent fuel bundle will see significant heat reduction after hundreds of thousands of years. Reprocessing, which extracts plutonium, one of the transuranics, and incorporates that plutonium into mixed oxide fuel which is burned in light water reactors, is improved over a repository because it extracts plutonium. However, reprocessing will see significant heat reduction after thousands of years. Recycling, on the other hand, fuels a sodium-cooled reactor with all of the transuranics. Because the transuranics are almost completely burned up and consumed as power is generated by the reactor, they are not part of the waste stream and that significantly reduces the heat load on the repository to hundreds of years rather than thousands or hundreds of thousands of years.

With that, I have four recommendations for the Committee. First, work with industry to drive research, development and demonstration for recycling. GE Hitachi has developed a framework for research on closing the fuel cycle and we have actually submitted that to Michelle[1] in advance of this testimony. We recognize the critical importance of working with our national labs and our universities in advancing research and development work in support of this effort. Number two, fund research that leads to logical development in areas like licensing, manufacturing and design validation and advanced separation technologies. Three, we should continue to fund basic research in advanced technologies for closing the fuel cycle. And lastly, we should fund demonstrations that will provide the data that will support an informed decision on commercially deploying potential back-end fuel cycle solutions.

The Nation has an opportunity today to lead a transformation to a new, safer and more secure approach to nuclear energy and recycling with a sodium-cooled reactor and electro-metallurgical processing can close the fuel cycle. Our technology and our solution approach meets the government's goals. It generates additional incremental carbon-free electricity. It provides enhanced energy security. It provides additional options for geologic storage greater than that which exists today. It can reduce proliferation concerns and nuclear waste volumes, and importantly, it positions the United States to be in a unique position to exert its leadership once again in nuclear science and technology.

Thank you, Mr. Chairman and the Committee.

[The prepared statement of Ms. Price follows:]

PREPARED STATEMENT OF LISA M. PRICE

Mr. Chairman, Congressman Hall, and Members of the Committee, I appreciate this opportunity to provide you with a description of a suggested approach to managing Used Nuclear Fuel (UNF) from our nation's fleet of nuclear power reactors. GE Hitachi Nuclear Energy (GEH) has developed this approach based on technology originally developed with funding from the Department of Energy. We believe that with well-focused research and development and timely demonstrations, the United States can move toward closing the nuclear fuel cycle. Closing the fuel cycle would mean changing our nuclear fuel management philosophy from "once through" with repository management to near total consumption of the fuel's energy and considerably reduced repository management of the waste. Our current (and growing) inventory of "once through" used nuclear fuel is an energy asset. We can realize maximum value of this asset by:

1. utilizing established processes—which importantly do not separate pure plutonium, thus markedly reducing proliferation concerns—to recycle the fuel into a usable form;
2. refissioning the recycled fuel in a sodium-cooled reactor to produce electricity, which helps meet growing demand for electricity; and
3. producing final waste by this process that has significantly reduced radiological toxicity, which allows for improved repository characteristics and

[1] Energy and Environment Majority Professional Staff Michelle Dallafior

shorter management time as compared to "once through" and reprocessing technologies currently in use today.

Abundant, reliable and sustainable energy is essential for the health, safety and productivity of society. Nuclear power supplies approximately 20 percent of the electricity generated in the United States, and many other countries are pursuing nuclear power as to meet growing energy needs. The United States needs to strengthen our research and development to participate in and lead in this growth. GEH supports the Committee's evaluation of recycling approaches to closing the nuclear fuel cycle as foundational to realizing the benefits of increased nuclear power production to meet our own demand for electricity. In so doing, we will be positioned to make real and significant contributions to meeting international energy security needs as well.

In my previous roles as GE's General Manager of Global Business Development at GE Corporate and GE Energy, I developed an understanding of the complex financing issues facing new approaches in the market place. In my current roles as Senior Vice President, GEH and Chief Executive Officer of Global Nuclear Fuel, LLC, I am working to integrate the Advanced Recycling Center, comprised of a sodium-cooled reactor with an electro-metallurgical nuclear fuel recycling facility, into our nation's energy mix. I will describe the Advanced Recycling Center later in my testimony. Recently GEH has been working with our nation's national laboratories, universities, and some of our allies abroad in advancing this technology to close the fuel cycle.

Mr. Chairman, based on the focus of this session, I have divided my testimony into two broad areas: First, why should the U.S. pursue Nuclear Fuel Recycling? Then, what reasoned Research, Development, and Demonstration strategies could be properly formulated to advance the technology? Within these broad areas I will provide a detailed summary of mutually supportive transformational technologies to recycling nuclear fuel. We believe this approach presents a different and compelling option for the Committee to consider as a viable solution for managing used nuclear fuel in the United States, and advancing the nuclear renaissance.

**Why Consider Recycling?**

The U.S. position on nuclear energy and the potential for PRISM technology was articulated earlier this year:

> *"Looking towards the future, our Department of Energy is currently restructuring its fuel cycle activities, which were previously focused on the near-term deployment of recycling processes and advanced reactor designs, into a long-term, science-based, research and development program focused on the technical challenges associated with managing the back end of the fuel cycle. These challenges will be thoroughly vetted and resolved as we explore long-term solutions for management and disposition of our spent nuclear fuel."*
>
> Ambassador Schulte's Remarks on Behalf of Energy Secretary Chu, IAEA international Ministerial Conference, Beijing, April 2022, 2009.

We can continue down the same path for used nuclear fuel that we have been on for the last thirty years, or we can lead a transformation to a new, safer, and more secure approach to nuclear energy. We need an approach that brings the benefits of nuclear energy to the world while reducing proliferation concerns and nuclear waste. But first I would like to share how we define recycling.

In response to recent interest in increasing the use of nuclear power to produce electricity, the options for solving the nuclear waste problem boil down into what I call the three Rs: Repository, Reprocess, Recycle. Ideally, government policy should accelerate the most comprehensive science-based solution.

The three policy choices available for managing nuclear waste are:

Repository—sequestering used fuel in a permanent Repository.

Reprocess—placing the plutonium from the used nuclear fuel into Mixed Oxide (MOX) fuel for use in existing light water reactors. Reprocessing places the fission products and high-heat-load transuranics (also known as actinides) in a permanent Repository.

Recycle—fueling a sodium-cooled reactor with the long half-life transuranics from used fuel. Recycling places a much smaller heat-generating load (predominantly fission products) in a Repository. These shorter-lived elements only require that the repository be managed as a high level waste facility for a few hundred years.

Our efforts have led us to conclude that the Recycling approach is the best science-based solution, whereas Reprocessing is only considered a temporary or intermediate solution, even in the countries where it is used today (UK, France, and Japan). These countries continue to pursue a long-term option of recycling using sodium-cooled reactors, though over a much longer time frame than we believe would be needed by leveraging U.S. technology.

It is important to understand the basic science to better understand the three Rs. Two questions must be answered for a full understanding of the three Rs: 1) what is the composition of nuclear waste and 2) what is the proper metric for making policy choices regarding Repository, Reprocess, or Recycle?

Composition of nuclear waste: Uranium is a naturally occurring metal mined from the Earth. The raw uranium commodity has value added by conversion from ore to near-pure uranium, by enrichment to raise the concentration of $U^{235}$ from 0.7 percent to approximately 5.0 percent, and by fabrication into fuel rods that are packaged into a fuel bundle that is sold to the utility to be fissioned in the core of a nuclear power reactor. In the reactor, the nuclear fuel bundle produces heat for several years until most of the $U^{235}$ is consumed, taking it from an initial five percent down to less than one percent. It is then a used fuel bundle to be removed from the reactor, defined by law as "high level nuclear waste." The composition of this "high level nuclear waste" is still 95 percent uranium dioxide, with new fission products (about four percent), and new transuranics (about one percent). This one percent of transuranics (elements bigger than uranium such as neptunium (Np), plutonium (Pu), americium (Am) and curium (Cm)) generates "99.9" percent of the public policy concerns.

Correct science metric for evaluation: In the public mind, and even in the legislation providing for the Yucca Mountain Repository, the terms "mass" and "volume" are used. However, mass and volume are not the most important concerns in managing nuclear waste; heat is—a reality that has implications for this public policy.

Nuclear fuel is unique in that its radioactivity heats the used fuel and its surroundings. The heat generated—the energy released—over the long-term by the radioactive components that have a long-half life is the limiting factor. The four principal transuranics in the nuclear spent fuel—Np, Pu, Am, and Cm, produce the majority of the long-term heat. Reducing transuranics in waste to be sent to a repository reduces long-term heat generation from 100,000s of years to hundreds of years, so processes that provide the opportunity to consider broader geological characteristics of a repository will need to reduce long-term heat from transuranics. This means that, although mass and volume are important considerations, they are not the most significant issues for a repository, heat is.

Recognizing the significance of long-term heat generation, let's compare the three Rs. Figure 1 shows the reduction in heat over time for each of the three Rs:

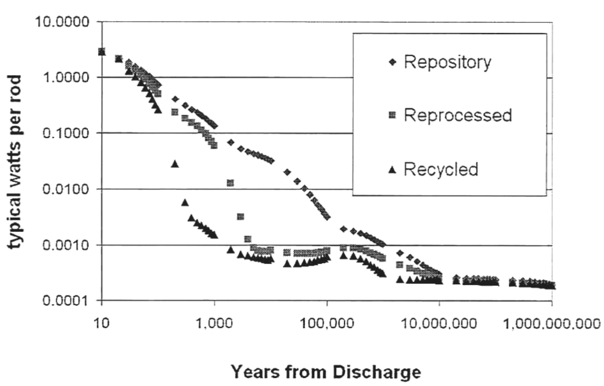


**Figure 1:** Long-Term Heat Generation Consequences—Repository, Reprocess, Recycle

The line labeled "Repository" shows how the long-term heat generation—the radioactivity—of a typical used nuclear fuel bundle from a contemporary commercial nuclear power reactor decreases over time in an underground Repository. A typical used fuel bundle has significant heat reduction after hundreds of thousands of years.

The “Reprocessing” line shows the long-term decline in the heat generated by vitrified waste, the waste product of the currently established aqueous reprocessing of Light Water Reactor (LWR) fuel that would be placed into a Repository. Reprocessing has significant heat reduction after a thousand years.

The line labeled “Recycling” shows the long-term heat generation of the “real” waste—the metallic and ceramic waste from used nuclear fuel. The impacts from the Recycling option are markedly reduced because almost all of the transuranics—the producers of significant long-term heat loading—are separated and consumed (or fissioned) in the sodium-cooled reactor as it generates power so they are not part of the waste stream that goes to the Repository.

Note that each of the three Rs do produce waste that must be isolated. We need to be clear that long-term storage—a repository—for nuclear waste will be needed for any of these options. The required isolation time, however, depends on the strategy selected—hundreds of thousands of years for the direct Repository option, thousands of years for the Reprocessing option, versus hundreds of years for the Recycling option.

Each “R” encompasses niche processes that have some variations—such as composition of Repository host rock; choice of aqueous MOX Reprocessing technology (PUREX, UREX, NUEC, COEX); separations technology for Recycling (aqueous or electro-metallurgy); kind of sodium-cooled reactor (loop versus pool); consumption ratios—but these variations have only minor effects on the conclusion that can be drawn from the data presented above.

Further, light water reactors cannot operate at the high burn up rates to consume transuranics, so the comparison of Reprocessing and Recycling are fundamental. Thus, general conclusions for each of the three scenarios can be improved by optimizing its contributing variables, but prior to optimization a path to the solution needs to be identified. My staff can provide more details if the Committee desires.

**PRISM, a Gen IV solution**

The Department of Energy is seeking “. . . a long-term, science-based research and development program focuses on the technical challenges associated with managing the back end of the fuel cycle.” We think we can sharpen that focus by leveraging from past lessons from the Advanced Liquid Metal Reactor Program (ALMR). The ALMR program was started in 1984 to develop sodium-cooled reactors for a variety of missions including: better utilization of energy in uranium, minimization of proliferation concerns by consuming weapons grade plutonium, and consumption of (via fission) long half-life transuranics in used nuclear fuel, thus reducing the long-term heat loading in a geologic repository. This program was on track to deploy a sodium-cooled reactor to consume used LWR fuel while producing electricity. Unfortunately, the ALMR project ended in 1995. Subsequently, the DOE shut down EBR–II (in Idaho) and the Fast Flux Test Facility (FFTF—a sodium reactor in Washington State), two outstanding sodium-cooled reactors. These actions cast the U.S. advanced nuclear reactor programs adrift and diminished the leadership role the U.S. had played in nuclear power research and development.

With the growing recognition that a portion of our future energy needs should be met using nuclear power, resurrecting, improving and implementing the R&D path set by ALMR program would be a prudent starting point. By conducting research and development of sodium-cooled reactor technology, the U.S. can regain technology leadership and create thousands of good, high quality long-term jobs.

The ALMR program coupled two technologies together in a balanced system: 1) the sodium-cool reactor, and 2) separations technology based on a dry process (without water) using molten salts. Again my staff and the previous work by the GEH team can provide numerous details about these two technologies and the science behind them. Briefly, the environmental impetus for sodium-cooled reactor development is three fold: 1) reduce mineral resource extraction (the mining of uranium), 2) significantly decrease radiotoxicity (half-life) of long-lived constituents in LWR used fuel (transuranics) from millions of years to a few hundred years; and 3) produce large amounts of carbon-emission free power.

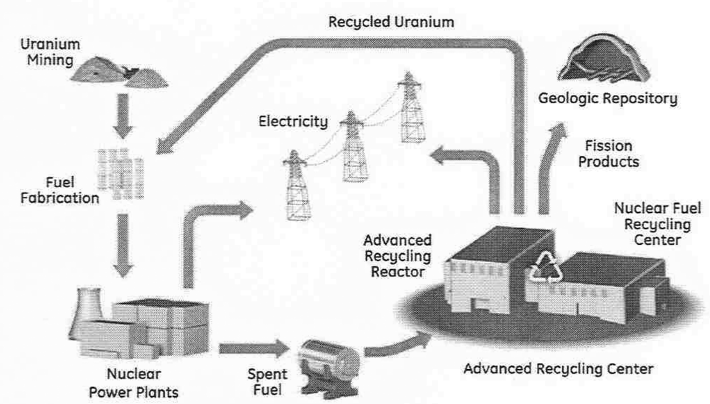


**Figure 2**: GEH Advanced Recycling Center to close the fuel cycle in the future.

Figure 2 illustrates the closed fuel cycle. Fuel from existing plants is transported to a facility that separates the fuel into three constituents. The three constituents are 1) uranium that is recycled for use in LWR reactors, 2) transuranics (Pu, Np, Cm and others) that are used to fuel a sodium-cooled reactor and 3) fission product wastes that are to be placed in a geological repository.

To understand the transformational shift the sodium-cooled reactor coupled with dry processing in our Advanced Recycling Center would establish within the nuclear power arena, it is helpful to consider an analogy to internal combustion engine development. In 1892 the gas combustion engine was patented using gasoline, a waste product from crude oil processing. Diesel engine development, started in 1898, used another portion of crude oil. Both gas and diesel engines release energy from combustion, but the methods to initiate combustion are fundamentally different. Which internal combustion engine is better? Neither—both are functional, are not detrimental to the other, and improve the total fuel cycle use from a single petroleum energy source. Shifting to nuclear power, the current commercial market is approximately $30 billion based on one technology—water moderated reactors (grouping light water & heavy water reactors together). Sodium-cooled reactors are transformational and add a new functional market segment and technology. Which reactor type is better? Neither—both are functional, are not detrimental to the other, and improve the total fuel cycle from the nuclear energy source. Energy from Earth's uranium is better utilized by the symbiotic combination of water and sodium reactors. The long-lived radioactive transuranics elements (Np, Pu, Am, and Cm) from used water-cooled reactor fuel are now fuel in the sodium-cooled reactor. Additionally, excess plutonium from this nation's weapons program can be used as start-up fuel for initial demonstrations.

GEH ideas for Research, Development, and Demonstration of the transformational solutions are presented in the next section. Each step is critical to advancing technology for nuclear fuel recycling. Policy decisions about paths to take in dealing with nuclear waste can be made now.

**Advancing Technology for Nuclear Fuel Recycling**

As this Committee searches for policy options for "Advancing Technology for Nuclear Fuel Recycling," please consider the merits of more integrated science-based solutions. Funding to advance sodium-cooled reactors would provide the foundation for science-based R&D for cross-cutting solutions to challenges facing the Nation in a variety of areas, including:

**Nuclear Waste Disposal:** What is the best solution for nuclear waste disposal? Solution: Through science, prove that transuranics (Np, Pu, Am, and Cm) contained in used nuclear fuel can fuel a sodium-cooled reactor. The "waste," or fission products, from such a reactor has significantly reduced long-term radiotoxicity. As discussed above this strategy significantly reduces the time frame for safe and secure waste management within a geologic repository.

**Nuclear Energy:** What is the spark to build advanced light water reactor technology, and focus Generation IV & Fuel Cycle R&D? Solution: A bold leadership move to support advanced sodium-cooled technology would lower Greenhouse Gas (GHG) emissions from power generation, supply clean secure energy, improve economic prosperity through job creation and enhance national security through initial plutonium consumption. Starting this work now would improve market confidence that there is a future for nuclear power.

**NNSA:** Fissile Materials Disposition alternatives? Solution: Disposition of five metric tons of plutonium (melting classified shapes with the correct amount of uranium and zirconium, producing the metallic alloy UPuZr) to start up the PRISM. This would eliminate the costly plutonium purification step needed when weapons plutonium is used as LWR fuel and support the re-establishment of U.S. international leadership.

Many technologists and industry participants globally agree that the sodium-cooled reactor is needed; however, some claim that further research is needed and that this technology can wait until 2050. In contrast, GEH is pleased to share ideas that should be pursued in Research, Development and Demonstration in the near-term.

**. . . Our Ideas for Research**

GEH published *"GE Hitachi Nuclear Energy Technology Development Roadmap: Facilities for Closing the Fuel Cycle,"* which outlines the framework for focused research.

While GE has Global Research centers that tackle the pure basic research issues, our Fuel Cycle Business does not actively perform basic science research. That is not our role, nor is it our domain expertise. That said, we recognize that we must partner with the experts at our national laboratories and universities.

Recently GEH has been working with several national laboratories, including, Argonne, Idaho, Los Alamos, Oak Ridge and Savannah River, on the research that is needed to close the nuclear fuel cycle. Further, we have been working with select universities in basic research activities to close the nuclear fuel cycle. Lastly GEH has supported universities in Nuclear Energy Research Initiatives–Consortium (NERI–C) in science research needed to close the fuel cycle.

We cannot emphasize enough our support for the strong science role of our nation's national laboratories and universities in this area. However, we must accompany basic research with applied research. By combining basic and applied research, we will explore new frontiers while developing solutions to our pressing problems.

**. . . Our Ideas for Development**

GEH continues to be a leader in nuclear science and technology through our ability to bring products to market. We have expertise and internal processes for quality, new product introduction, risk assessments, environmental, health & safety, licensing and regulatory programs. We are looking into broad areas of isotope development, and next-generation laser enrichment technologies, in addition to our work on closing the nuclear fuel cycle.

We see such Development as a key area where industry (GEH) can work with the national labs and the DOE in support of this committee's goal of coming up with science-based solutions to nuclear waste issues. Specifically, I'd like to offer these suggestions:

1) **Licensing:** A sodium-cooled reactor that produces power requires (among other things) a license from the U.S. Nuclear Regulatory Commission. Therefore, a development path similar to Congress' *Energy Policy Act* (EPACT) 2005 Nuclear Title on Next Generation Nuclear Plant (NGNP) licensing activities would produce the required Tier 1 and Tier 2 Design Control Documents for preliminary submittal to the NRC. Developing the Design Control Documents will help focus research while clarifying the feasibility and timeframe for sodium cooled reactor development.

2) **Manufacturing & Design Validation:** U.S.-based fabrication, transportation, and placement of a full-sized PRISM reactor vessel at a U.S. university (as a user facility). The vessel would be filled with water (to simulate sodium) to improve component and system technology readiness levels of the reactor system. This R&D platform would offer several benefits: reduced risk, shortened time for licensing activities, expanded U.S. manufacturing base, and availability of an advanced R&D platform for U.S. universities and national laboratories. After the manufacturing

and design validation phase, the next step would be fabrication of a second PRISM reactor vessel to be located at a U.S. national laboratory, which would be filled with sodium to further the development process (as discussed below).

3) **Separation Technology Advancement:** While basic research is needed in transuranic separations, dry, electro-metallurgical, processing can be advanced by demonstrations using excess uranium. Commercial and government facilities have uranium that is too contaminated to use in commercial reactors. By developing an electro-metallurgical processing demonstration facility, the uranium can be unlocked while advancing the science needed to perform advanced separations on used fuel.

**. . . Our Ideas for Demonstration**

Future technology performance can be difficult to establish. Therefore, GEH regularly assesses the future potential of a tool, technology, and reactor concept improvement through a Demonstration. Demonstration is an integral part of the Research and Development process. A future demonstration of the sodium-cooled reactor and separations processes will allow us to gather important technical information that will position the technology for success. Two demonstrations are needed:

1. Fabricate (in the U.S.), transport, and place a full-sized PRISM reactor vessel at a U.S. national laboratory (as a user-demonstration facility). Fill this vessel with sodium to improve component and system technology readiness levels of the reactor system, through large-scale demonstration of technologies proved in the Research and Development component. After this is completed this Science and Technology Committee and other key decision-makers will be in a position to evaluate the data and performance to make an informed choice about cost and schedule to implement the Recycling solution.
2. Operate an electro-metallurgical demonstration of used nuclear fuel at one of the following locations: INL (leveraging previous EBR–II facilities), or PNNL (leveraging the previously built, but never used Fuels Materials Examination Facility (FMEF)), or potentially GEH's Morris, IL facility. This demonstration would help transition Research & Development activities on uranium recovery to the more difficult demonstration with used nuclear fuel, with its inherent high radiation issues.

**Summary of Recommendations**

My recommendations for the Committee when developing a strategy to "Advance Technology for Nuclear Fuel Recycling" in the area of Research, Development and Demonstration are:

1) Work with industry to drive the Research, Development and Demonstration of Recycling—the most comprehensive solution for used nuclear fuel
2) Fund Research that builds to logical Development and is followed by meaningful Demonstrations
3) Continue to fund basic Research activities to look for advanced solutions on closing the nuclear fuel cycle with input from industry and others
4) Fund Demonstrations to provide meaningful data on economics, operating performance and risks, and schedule risks that will support informed decisions regarding future commercial activities.

Our nation has already made much of the necessary investment in facilities, analysis, study, research and experimentation on the foundation necessary to support the design and deployment of sodium-cooled reactors. The national laboratories have amassed extensive documentation and proof of the PRISM concept, its safety, and its viability. We should take advantage of that wealth of knowledge and expertise, and move ahead with a comprehensive Research, Development and Demonstration program. As the last U.S. majority owned reactor vendor, GEH is ready to partner with the Federal Government in this important effort.

The Nation faces a choice today: We can continue down the same path that we have been on for the last thirty years or we can lead a transformation to a new, safer, and more secure approach to nuclear energy, an approach that brings the benefits of nuclear energy to the world while reducing proliferation concerns and nuclear waste.

PRISM coupled with electro-metallurgical processing is a technology solution that can close the nuclear fuel cycle using the energy contained in our nation's spent nuclear fuel. PRISM can generate stable base load electricity to help meet our growing electricity needs and enhance our energy security. As we do so, we expand the options for geologic storage. A choice to go down the path of Recycling will provide a unique opportunity to regain the historical U.S. leadership position in nuclear science and technology.

Thank you. This concludes my formal statement. I would be pleased to answer any questions you may have at this time.

BIOGRAPHY FOR LISA M. PRICE

Lisa was named Senior Vice President, GE Hitachi Nuclear Energy (GEH) and Chief Executive Officer of Global Nuclear Fuel, LLC, the legal entity that manages the Global Nuclear Fuel joint venture of GE, Hitachi and Toshiba, headquartered in Wilmington, North Carolina in April 2008. In her role Lisa leads all nuclear fuel cycle activities for GEH, including the global BWR fuel business, advanced programs and the recently formed laser enrichment business.

Lisa joined GEH from her most recent role as General Manager, Business Development for GE Energy, an prior to that for GE Corporate. In these roles she and her team successfully completed numerous transactions that added to the inorganic growth of GE and GE Energy.

Lisa earned a BS in Chemical Engineering from Virginia Polytechnic Institute & State University and an MBA from Tulane University. After earning her MBA, Lisa spent nearly eight years at Goldman, Sachs & Co. and two years at Deutsche Bank, where she focused on mergers and acquisitions in the energy, utility and oil & gas industries. Prior to that, Lisa served in a variety of operating and environmental positions with FreeportMcMoRan, Inc., including power plant operating roles with Freeport Sulphur Company, Corporate Environmental Auditing program leader and Environmental Manager for Agrico Chemical Company's Louisiana Chemical Operations. Lisa joined GE in 2005.

Lisa serves on the Virginia Tech College of Engineering Advisory Board and is a member of the Committee of 100. Lisa is also a member of Women in Nuclear.

Chairman GORDON. Thank you, Ms. Price.

Dr. Ferguson, you are recognized.

**STATEMENT OF DR. CHARLES D. FERGUSON, PHILIP D. REED SENIOR FELLOW FOR SCIENCE AND TECHNOLOGY, COUNCIL ON FOREIGN RELATIONS**

Dr. FERGUSON. Thank you, Mr. Chairman, Dr. Ehlers and Members of the Committee for inviting me to testify. I request that my written comments be entered into the official record. In the following remarks I briefly discuss major findings and recommendations based on the written testimony.

The United States has sought to prevent the spread of reprocessing facilities to other countries and to encourage countries with existing stockpiles to separate plutonium from reprocessing facilities to draw down those stockpiles. The United States should reaffirm and strengthen this policy. Reprocessing of the type currently practiced in a handful of countries poses a significant proliferation threat because the separation of plutonium from highly radioactive fission products separates it from a protected barrier against theft. A thief, if he had access, could easily carry away separated plutonium. Fortunately, this reprocessing is confined to nuclear arms states except for Japan. If this practice spreads to other non-nuclear weapons states, the consequences for national and international security could be dire.

Presently, the vast majority of the 31 states with nuclear power programs do not have reprocessing plants. U.S. policy has been effective in setting an example in limiting the spread of reprocessing. Japan, France and Russia launched their reprocessing programs before U.S. policy that was set in the Ford Administration in 1976 and reaffirmed in the Carter Administration in 1977, but we see that two countries in particular are of concern. The Republic of Korea is renewing its 123 agreement with the United States. As I point out in my written testimony, they are interested in reprocessing. We need to reaffirm that reprocessing is not something that should be done on the Korean Peninsula, especially when we are dealing with a nuclear-armed North Korea. The United Arab Emirates in its 123 agreement has a clause at the very end of the agreement on equal terms and conditions that could open the door to the UAE engaging in reprocessing or uranium enrichment in the future, depending on what other countries in the Middle East do, especially Jordan. I was just in Jordan two months ago and found out their plans.

Global stockpiles of civilian plutonium are growing at about 250 metric tons, equivalent to tens of thousands nuclear bombs or comparable to the global stockpile of military plutonium, and more than 1,000 metric tons of plutonium is contained in spent nuclear fuel in about 30 countries. The types of reprocessing that were examined under the Global Nuclear Energy Partnership, or GNEP, do not appear to offer substantial proliferation-resistant benefits according to research sponsored by the Department of Energy. Moreover, the DOE assessment points out that these techniques pose additional safeguard challenges. For example, it is difficult to do an accurate accounting of the amount of plutonium in a bulk handling reprocessing facility that produces plutonium mixed with other transuranic elements. This challenge raises the probability of diversion of plutonium by insiders. However, more research is needed to determine what additional safeguards could provide greater assurances that reprocessing methods are not misused in weapons programs and whether it is possible to have assurances of timely detection of a diversion of a significant quantity of plutonium or other fissile material.

Time is on the side of the United States. There is no need to rush toward development and deployment of recycling of spent nuclear fuel. Based on the foreseeable price for uranium and uranium enrichment services and the known reserves of uranium, this practice is presently far more expensive than the once-through uranium fuel cycle. Nonetheless, more research is needed to determine the cost and benefits of recycling techniques coupled with fast neutron reactors or other types of reactor technologies. This cost-versus-benefit analysis would concentrate on the capability of these technologies to help alleviate the nuclear waste management challenge.

In related research, there is a need to better understand the safeguards challenges in the use of fast reactors. Such reactors are dual use in the sense that they can burn transuranic material or can breed new plutonium. In the former operation, they could provide a needed nuclear waste management benefit but they are expensive. In the latter operation, they can pose a significant proliferation threat because they obviously breed more plutonium.

Concerning lessons the United States can learn from other countries' nuclear waste management experience, the first lesson is that a fair political and sound scientific process is essential for selecting a permanent repository. The second lesson is that reprocessing as currently practiced does not substantially alleviate the nuclear waste management problem. Any type of reprocessing will require safe and secure repositories.

I will also add another recommendation from my written remarks, is that we need better estimates on the remaining global reserves of uranium. It is believed based on current demand we have probably another 80 years worth of supply and maybe much greater than that. The MIT study that was just updated a few weeks ago makes this one of their major recommendations.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Ferguson follows:]

PREPARED STATEMENT OF CHARLES D. FERGUSON

## An Assessment of the Proliferation Risks of Spent Fuel Reprocessing and Alternative Nuclear Waste Management Strategies

Mr. Chairman, thank you for inviting me to testify on the nuclear proliferation challenges of reprocessing spent nuclear fuel and effective ways for reducing those proliferation risks through federal research, development, and demonstration initiatives. In this testimony, I also discuss nuclear waste management programs deployed by other nations and examine whether those programs represent alternative management strategies that the U.S. Federal Government should consider.

U.S. leadership is essential for charting a constructive and cooperative international course to prevent nuclear proliferation. An essential aspect of that leadership involves U.S. policy on reprocessing spent nuclear fuel. The United States has sought to prevent the spread of reprocessing facilities to other countries and to encourage countries with existing stockpiles of separated plutonium from reprocessing facilities to draw down those stockpiles. The previous administration launched the Global Nuclear Energy Partnership (GNEP), which proposed offering complete nuclear fuel services, including provision of fuel and waste management, from fuel service states to client states in order to discourage the latter group from enriching uranium or reprocessing spent nuclear fuel—activities that would contribute to giving these countries latent nuclear weapons programs. The current administration and the Congress seek to determine the best course for U.S. nuclear energy policy with the focus of this hearing on recycling or reprocessing of spent fuel and nuclear waste management strategies.

Here at the start, I give a brief summary of the testimony's salient points:

- Reprocessing of the type currently practiced in a handful of countries poses a significant proliferation threat because of the separation of plutonium from highly radioactive fission products. A thief, if he had access, could easily carry away separated plutonium. Fortunately, this reprocessing is confined to nuclear-armed states except for Japan. If this practice spreads to other non-nuclear-weapon states the consequences for national and international security could be dire. Presently, the vast majority of the 31 states with nuclear power programs do not have reprocessing plants.
- The types of reprocessing examined under GNEP do not appear to offer substantial proliferation-resistant benefits, according to research sponsored by the Department of Energy. However, more research is needed to determine what additional safeguards, if any, could provide greater assurances that reprocessing methods are not misused in weapons programs and whether it is possible to have assurances of timely detection of a diversion of a significant quantity of plutonium or other fissile material.
- Time is on the side of the United States. There is no need to rush toward development and deployment of recycling of spent nuclear fuel. Based on the foreseeable price for uranium and uranium enrichment services, this practice is presently far more expensive than the once-through uranium fuel cycle. Nonetheless, more research is needed to determine the costs and benefits of recycling techniques coupled with fast-neutron reactors or other types of reactor technologies. This cost versus benefit analysis would concentrate on the capability of these technologies to help alleviate the nuclear waste management challenge.

- In related research, there is a need to better understand the safeguards challenges in the use of fast reactors. Such reactors are dual-use in the sense that they can burn transuranic material and can breed new plutonium. In the former operation, they could provide a needed nuclear waste management benefit. In the latter operation, they can pose a serious proliferation threat.

**Proliferation Risks**

Reprocessing involves extraction of plutonium and/or other fissile materials from spent nuclear fuel in order to recycle these materials into new fuel for nuclear reactors. As discussed below, many reprocessing techniques are available for use. Regardless of the particular technique, fissile material is removed from all or almost all of the highly radioactive fission products, which provide a protective barrier against theft or diversion of plutonium in spent nuclear fuel. Plutonium-239 is the most prevalent fissile isotope of plutonium in spent nuclear fuel. The greater the concentration of this isotope the more weapons-usable is the plutonium mixture. Weapons-grade plutonium typically contains greater than 90 percent plutonium-239 whereas reactor-grade plutonium from commercial thermal-neutron reactors has usually less than 60 percent plutonium-239, depending on the characteristics of the reactor that produced the plutonium. The presence of non-plutonium-239 isotopes complicates production of nuclear weapons from the plutonium mixture, but the challenges are surmountable.[1] According to an unclassified U.S. Department of Energy report, reactor-grade plutonium is weapons-usable.[2]

The potential proliferation threats from reprocessing of spent nuclear fuel are twofold. First, a state operating a reprocessing plant could use that technology to divert weapons-usable fissile material into a nuclear weapons program or alternatively it could use the skills learned in operating that plant to build a clandestine reprocessing plant to extract fissile material. Second, a non-state actor such as a terrorist group could seize enough fissile material produced by a reprocessing facility in order to make an improvised nuclear device—a crude, but devastating, nuclear weapon. Such a non-State group may obtain help from insiders at the facility. While commercial reprocessing facilities have typically been well-guarded, some facilities such as those at Sellafield in the United Kingdom and Tokai-mura in Japan have not been able to account for several weapons' worth of plutonium. This lack of accountability does not mean that the fissile material was diverted into a State or non-State weapons program. The discrepancy was most likely due to plutonium caked on piping. But an insider could exploit such a discrepancy. For commercial bulk handing facilities, several tons of plutonium can be processed annually. Thus, if even one tenth of one percent of this material were accounted for, an insider could conceivably divert about one weapon's worth of plutonium every year.

Location matters when determining the proliferation risk of a reprocessing program. That is, a commercial reprocessing plant in a nuclear-armed state such as France, Russia, or the United Kingdom poses no risk of State diversion (but could pose a risk of non-state access) because this type of state, by definition, already has a weapons program. Notably, Japan is the only non-nuclear-armed state that has reprocessing facilities. Japan has applied the Additional Protocol to its International Atomic Energy Agency safeguards, but its large stockpile of reactor-grade plutonium could provide a significant breakout capability for a weapons program. (Chinese officials and analysts occasionally express concern about Japan's plutonium stockpile.) Since the Ford and Carter Administrations, when the United States decided against reprocessing on proliferation and economic grounds, the United States has made stopping the spread of further reprocessing facilities especially to non-nuclear weapon states a top priority.

Another top priority of U.S. policy on reprocessing is to encourage countries with stockpiles of separated plutonium to draw down these stockpiles quickly. This drawdown can be done either through consuming the plutonium as fuel or surrounding it with highly radioactive fission products. Global stockpiles of civilian plutonium are growing and now at about 250 metric tons—equivalent to tens of thousands of nuclear bombs—are comparable to the global stockpile of military plutonium. More than 1,000 metric tons of plutonium is contained in spent nuclear fuel in about thirty countries.

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[1] Richard L. Garwin, "Reactor-Grade Plutonium can be used to Make Powerful and Reliable Nuclear Weapons," Paper for the Council on Foreign Relations, August 26, 1998, available at: *http://www.fas.org/rlg/980826-pu.htm*. J. Carson Mark, "Explosive Properties of Reactor-Grade Plutonium," *Science and Global Security,* 4, 111–128, 1993.

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

While no country has used a commercial nuclear power program to make plutonium for nuclear weapons, certain countries have used research reactor programs to produce plutonium. India, notably, used a research reactor supplied by Canada to produce plutonium for its first nuclear explosive test in 1974. North Korea, similarly, has employed a research-type reactor to produce plutonium for its weapons program. Although nonproliferation efforts with Iran has focused on its uranium enrichment program, which could make fissile material for weapons, its construction of a heavy water research reactor, which when operational (perhaps early next decade) could produce at least one weapon's worth of plutonium annually, poses a latent proliferation threat. To date, Iran is not known to have constructed a reprocessing facility that would be needed to extract plutonium from this reactor's spent fuel. Further activities could take place in the Middle East and other regions. For instance, according to the U.S. Government, Syria received assistance from North Korea in building a plutonium production reactor. In September 2009, Israel bombed this construction site.

The United States has been trying to balance the perceived need by many states in the Middle East for nuclear power plants versus restricting these states' access to enrichment and reprocessing technologies. Presently, as an outstanding example, the U.S.–UAE bilateral nuclear cooperation agreement is before the U.S. Congress. Proponents of this agreement tout the commitment made by the UAE to refrain from acquiring enrichment and reprocessing technologies and to rely on market mechanisms to purchase nuclear fuel. However, the last clause in the agreement appears to open the door for the UAE to engage in such activities in the future:

EQUAL TERMS AND CONDITIONS FOR COOPERATION

> The Government of the United States of America confirms that the fields of cooperation, terms and conditions accorded by the United States of America to the United Arab Emirates for cooperation in the peaceful uses of nuclear energy shall be no less favorable in scope and effect than those which may be accorded, from time to time, to any other non-nuclear-weapon State in the Middle East in a peaceful nuclear cooperation agreement. If this is, at any time, not the case, at the request of the Government of the United Arab Emirates the Government of the United States of America will provide full details of the improved terms agreed with another non-nuclear-weapon State in the Middle East, to the extent consistent with its national legislation and regulations and any relevant agreements with such other non-nuclear-weapon State, and if requested by the Government of the United Arab Emirates, will consult with the Government of the United Arab Emirates regarding the possibility of amending this Agreement so that the position described above is restored.[3]

Such a request for amendment could be around the corner because Jordan is seeking to conclude a bilateral nuclear cooperation agreement with the United States, and it has expressed interest in keeping open the option to enrich uranium. Jordan has discovered large quantities of indigenous uranium and may want to "add value" to that uranium through enrichment. Jordan or any other Middle Eastern state has not yet expressed interest in reprocessing. U.S. leadership and practice in this issue will serve as an example for other states interested in acquiring new nuclear power programs.

**Proliferation-Resistant Reprocessing**

Can reprocessing be made more proliferation-resistant? "Proliferation resistance is that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or misuse of technology by the host state seeking to acquire nuclear weapons or other nuclear explosive devices."[4] No nuclear energy system is proliferation proof because nuclear technologies are dual-use. Enrichment and reprocessing can be used either for peaceful or military purposes. However, through a defense-in-depth approach, greater proliferation-resistance may be achieved. Both intrinsic features (for example, physical and engineering characteristics of a nuclear technology) and extrinsic features (for example, safeguards and physical barriers) complement each other to deter misuse of nuclear technologies

[3] Agreement for Cooperation between the Government of the United States of America and the Government of the United Arab Emirates Concerning Peaceful Uses of Nuclear Energy, May 21, 2009.

[4] Office of Nonproliferation and International Security, *A Nonproliferation Impact Assessment for the Global Nuclear Energy Programmatic Alternatives,* National Nuclear Security Administration, U.S. Department of Energy, Draft, December 2008, p. 26.

and materials in weapons programs. The potential threats that proliferation-resistance tries to guard against are:

- "Concealed diversion of declared materials;
- Concealed misuse of declared facilities;
- Overt misuse of facilities or diversion of declared materials; and
- Clandestine declared facilities."[5]

For each of these threats, a detailed proliferation pathway analysis can be done in order to measure the proliferation risk and to determine the needed, if any, additional safeguards. The U.S. Department of Energy has sponsored such analysis for proposed reprocessing techniques considered under GNEP.[6] These techniques include UREX+, COEX, NUEX, and Pyroprocessing, and they have been compared to the PUREX technique, which is the commercially used method. PUREX separates plutonium and uranium from highly radioactive fission products. It is an aqueous separations process and thus generates sizable amounts of liquid radioactive waste. UREX+, COEX, and NUEX are also aqueous processes. UREX+ is a suite of chemical processes in which pure plutonium is not separated but different product streams can be produced depending on the reactor fuel requirements. COEX and NUEX are related processes. COEX co-extracts uranium and plutonium (and possibly neptunium) into one recycling stream; another stream contains pure uranium, which can be recycled; and a final stream contains fission products. NUEX separates into three streams: uranium, transuranics (including plutonium), and fission products. Pyroprocessing uses electro-refining techniques to extract plutonium in combination with other transuranic elements, some of the rare Earth fission products, and uranium. This fuel mixture would be intended for use in fast-neutron reactors, which have yet to be proven commercially viable.

Can these reprocessing techniques meet the highest proliferation-resistance standard of the "spent fuel standard" in which plutonium in its final form should be as hard to acquire, process, and use in weapons as is plutonium embedded in spent fuel?[7] The brief answer is "no" because the act of separating most or all of the highly radioactive fission products makes the fuel product less protected than the intrinsic protection provided by spent fuel. In fact, Dr. E.D. Collins of Oak Ridge National Laboratory has shown that the radiation emission from these reprocessed products is 100 times less than the spent fuel standard.[8] In other words, a thief could carry these products and not suffer a lethal radiation dose whereas the same thief would experience a lethal dose in less than one hour of exposure to plutonium surrounded by highly radioactive fission products. But these methods may still be worth pursuing depending on a detailed systems analysis factoring in security risks on site and during transportation, the final disposition of the material once it has been recycled as fuel, as well as the costs and benefits of nuclear waste management.

According to DOE's draft nonproliferation assessment of GNEP, "for a state with pre-existing PUREX or equivalent capability (or more broadly the capability to design and operate a reprocessing plant of this complexity), there is minimal proliferation resistance to be found by [using the examined reprocessing techniques] considering the potential for diversion, misuse, and breakout scenarios."[9] Moreover, the DOE assessment points out that these techniques pose additional safeguards challenges. For example, it is difficult to do an accurate accounting of the amount of plutonium in a bulk handling reprocessing facility that produces plutonium mixed

[5] *Ibid,* p. 28.

[6] See, for example, many of the references cited in Office of Nonproliferation and International Security, *A Nonproliferation Impact Assessment for the Global Nuclear Energy Programmatic Alternatives,* National Nuclear Security Administration, U.S. Department of Energy, Draft, December 2008.

[7] Committee on International Security and Arms Control, National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium,* Washington, DC: National Academy Press, 1994.

[8] E.D. Collins, Oak Ridge National Laboratory, "Closing the Fuel Cycle Can Extend the Lifetime of the High-Level Waste Repository," American Nuclear Society 2005 Winter Meeting, November 17, 2005, p. 13.

[9] *A Nonproliferation Impact Assessment for the Global Nuclear Energy Programmatic Alternatives,* p. 69.

with other transuranic elements.[10] This challenge raises the probability of diversion of plutonium by insiders.[11]

Another set of considerations is the choice of reactors to burn up the transuranic elements. The DOE draft assessment examined several choices including light water reactors, heavy water reactors, high temperature gas reactors, and fast-neutron reactors. Only the fast-neutron reactors offered the most benefits in terms of net consumption of transuranic material. This material would have to be recycled multiple times in fast reactors to consume almost all of it. This is called a full actinide recycle in contrast to a partial actinide recycle with the other reactor methods. The benefit from a waste management perspective is that the amount of time required for spent fuel's radiotoxicity to reduce to that of natural uranium goes from more than tens of thousands of years for partial actinide recycle to about 400 years for the full actinide recycle.

The challenge of the full actinide route, however, is that fast reactors can relatively easily be changed from a burner mode to a breeder mode. That is, these reactors can breed more plutonium by the insertion of uranium target material. The perceived need for breeder reactors has driven a few countries such as France, India, Japan, and Russia to develop reprocessing programs.

**Alternative Nuclear Waste Management Programs of Other Nations**

Has reprocessing programs, to date, helped certain nations solve their nuclear waste problems? The short answer is, "no." Before explicating that further, it is worth briefly examining why these countries began these programs. About fifty years ago, when the commercial nuclear industry was just starting, concerns were raised about the availability of enough natural uranium to fuel the thousands of reactors that were anticipated. Natural uranium contains 0.71 percent uranium-235, 99.28 percent uranium-238, and less than 0.1 percent uranium-234. Uranium-235 is the fissile isotope and thus is needed for sustaining a chain reaction. However, uranium-238 is a fertile isotope and can be used to breed plutonium-239, a fissile isotope that does not occur naturally. Thus, if uranium-238 can be transformed into plutonium-239, the available fissile material could be expanded by more than one hundred times, in principle. This observation motivated several countries, including the United States, to pursue reprocessing.

A related motivation was the desire for better energy security and thus less dependence on outside supplies of uranium. France and Japan, in particular, as countries with limited uranium resources, developed reprocessing plants in order to try to alleviate their dependency on external sources of uranium. They had invested in these plants before the realization that the world would not run out of uranium soon. By the late 1970s, two developments happened that alleviated the perceived pending shortfall. First, the pace of proposed nuclear power plant deployments dramatically slowed. There were plans at that time for more than 1,000 large reactors (of about 1,000 MWe power rating) by 2000, but even before the Three Mile Island accident in 1979, the number of reactor orders in the United States and other countries slackened off although France and Japan launched a reactor building boom in the 1970s that lasted through the 1980s. By 2000, there was only the equivalent of about 400 reactors of 1,000 MWe size. Second, uranium prospecting identified enough proven reserves to supply the present nuclear power demand for several decades to come.

Because there is plentiful uranium at relatively low prices and the cost of uranium enrichment has decreased, the cost of the once-through uranium cycle is significantly less than the cost of reprocessing. However, because fuel costs are a relatively small portion of the total costs of a nuclear power plant, reprocessing adds a relatively small amount to the total cost of electricity. In France, the added cost is almost six percent, and in Japan about ten percent. Nonetheless, in competitive utility markets in which consumers have choices, most countries have not chosen the reprocessing route because of the significantly greater fuel costs. France and Japan have adopted government policies in favor of reprocessing and also have sunk many billions of dollars into their reprocessing facilities. The French government owns and controls the electric utility Electricité de France (EDF) and the nuclear industry Areva. Despite this extensive government control, a 2000 French government study determined that if France stops reprocessing, it would save $4 to $5 bil-

[10] J.E. Stewart et al., "Measurement and Accounting of the Minor Actinides Produced in Nuclear Power Reactors," Los Alamos National Laboratory, LA–13054–MS, January 1996, p. 21.

[11] Ed Lyman, "U.S. Nuclear Fuel Reprocessing Initiative: DOE Research Shows Technology Does Not Reduce Risks of Nuclear Proliferation and Terrorism," Fact Sheet, Union of Concerned Scientists, February 2006.

lion over the remaining life of its reactor fleet.[12] EDF assigns a negative value to recycled plutonium.

While France's La Hague plant is operating, Japan is still struggling to start up its Rokkasho plant, which is largely based on the French design. Thus, the costs of the Japanese plant keep climbing and will likely be more than $20 billion. While the Japanese government wants to fuel up to one-third of its more than 50 reactors with plutonium-based mixed oxide fuel, local governments tend to look unfavorably on this proposal.

Only a few other nations are involved with reprocessing. Russia and the United Kingdom operate commercial-scale facilities. China and India are interested in heading down this path. But the United Kingdom is moving toward imminent shut down of its reprocessing mainly due to lack of customers. Moreover, the clean up and decommissioning costs are projected to be many billions of dollars. Russia and France also lack enough customers to keep their reprocessing plants at full capacity. In early April, I visited the French La Hague plant and was told that it is only operating at about half capacity. France only uses mixed oxide fuel in 20 of its 58 light water reactors. Presently, less than 10 percent of the world's commercial nuclear power plants burn MOX fuel. As stated earlier, the demand for MOX fuel has not kept up with the stockpiled quantities of plutonium.

With respect to nuclear waste management, an important point is that reprocessing, as currently practiced, does little or nothing to alleviate this management problem. For example, France practices a once-through recycling in which plutonium is separated once, made into MOX fuel, and the spent fuel containing this MOX is not usually recycled once (although France has done some limited recycling of MOX spent fuel). The MOX spent fuel is stored pending the further development and commercialization of fast reactors. But France admits that this full deployment of a fleet of fast reactors is projected to take place at the earliest by mid-century. France will shut down later this year its only fast reactor, the prototype Phénix. Perhaps around 2020, France may have constructed another fast reactor, but the high costs of these reactors have been prohibitive. In effect, France has shifted its nuclear waste problem from the power plants to the reprocessing plant.

France's practice of transporting plutonium hundreds of miles from the La Hague to the MOX plant at Marcoule poses a security risk. While there has never been a theft of plutonium or a major accident during the hundreds of trips to date, each shipment contains many weapons' worth of plutonium. Thus, just one theft of a shipment could be an international disaster.

No country has yet to open a permanent repository. But the country with the most promising record of accomplishment in this area is Sweden. A couple of weeks ago, Sweden announced the selection of its repository site but admits that the earliest the site will accept spent fuel is 2023. Sweden had carefully evaluated three different sites and obtained widespread community and local government involvement in the decision-making process. France touts the benefits of the volume reduction of recycling in which highly radioactive fission products are formed into a glass-like compound, which is now stored at an interim storage site. By weight percentage, spent fuel typically consists of 95.6 percent uranium (with most of that being uranium-238), three percent stable or short-lived radioactive fission products, 0.3 percent cesium and strontium (the primary sources of high-level radioactive waste over a few hundred years), 0.1 percent long-lived iodine and technetium, 0.1 percent long-lived actinides (heavy radioactive elements), and 0.9 percent plutonium. But the critical physical factor for a repository is the heat load. For the first several hundred years of a repository the most heat emitting elements are the highly radioactive fission products. The benefit of a fast reactor recycling program could be the reduction or near elimination of the longer-lived transuranic elements that are the major heat producing elements beyond several hundred years.

Other countries may venture into reprocessing. Therefore, it is imperative for the United States to re-evaluate its policies and redouble its efforts to prevent the further spread of reprocessing plants to non-nuclear-weapon states. In particular, the Republic of Korea is facing a crisis in the overcrowded conditions in the spent fuel pools at its power plants. One option is to remove older spent fuel and place it in dry storage casks, but the ROK government believes this option may cost too much because of the precedent set by the exorbitantly high price paid for a low level waste disposal facility. Another option is for the ROK to reprocess spent fuel. While this will provide significant volume reduction in the waste, it will only defer the problem to storage of MOX spent fuel, similar to the problem faced by France. This option will run counter to the agreement the ROK signed with North Korea in the early

[12] *Economic Forecast Study of the Nuclear Option* (Planning Commission, Government of France, 2000), section 3.4.

1990s for both states to prohibit reprocessing or enrichment on the Korean Peninsula. A related option is to ship spent fuel to La Hague, but a security question is whether to ship plutonium back to the ROK. France would require shipment of the high level waste back to the ROK. Thus, the ROK will need a high level waste disposal facility. The main reason I raise this ROK issue at length is that the ROK and the United States have recently begun talks on the renewal of their peaceful nuclear cooperation agreement, which will expire in 2014. The United States has consent rights on ROK spent fuel because either it was produced with U.S.-supplied fresh fuel or U.S.-origin reactor systems. The ROK is seeking to have future spent fuel not subject to such consent rights by purchasing fresh fuel from other suppliers and by developing reactor systems that do not have critical components that are U.S.-origin or derived from U.S.-origin systems. The bottom line is that the United States is steadily losing its leverage with the ROK and other countries because of declining U.S. leadership in nuclear power plant systems and nuclear waste management.

Concerning lessons the United States can learn from other countries' nuclear waste management experience, the first lesson is that a fair political and sound scientific process is essential for selecting a permanent repository. Sweden demonstrates the effectiveness of examining multiple sites and gaining buy-in from the public and local governments. The second lesson is that reprocessing, as currently practiced, does not substantially alleviate the nuclear waste management problem. However, more research is needed to determine the costs and benefits of fast reactors for reducing transuranic waste. Any type of reprocessing will require safe and secure waste repositories.

While the United States investigates the costs and benefits of various recycling proposals through a research program, it has an opportunity now to exercise leadership in two waste management areas. First, as envisioned in GNEP, the United States should offer fuel leasing services. As part of those services, it should offer to take back spent fuel from the client countries. (Russia is offering this service to Iran's Bushehr reactor.) This spent fuel does not necessarily have to be sent to the United States. It could be sent to a third party country or location that could earn money for the spent fuel storage rental service. Spent fuel can be safely and securely stored in dry storage casks for up to 100 years. Long before this time ends, a research program will most likely determine effective means of waste management. The spent fuel leasing could be coupled to the second area where the United States can play a leadership role. That is, the United States can offer technical expertise and political support in helping to establish regional spent fuel repositories. A regional storage system would be especially helpful for countries with smaller nuclear power programs.

**Recommendations**

- Continue to discourage separation of plutonium from spent nuclear fuel.
- Limit the spread of reprocessing technologies to non-nuclear weapon states.
- Draw down the massive stockpile of civilian plutonium.
- Support a research program to assess the costs and benefits of various reprocessing technologies with attention focused on proliferation-resistance, safeguards, and nuclear waste management. Compare the costs and benefits of reprocessing to enrichment, factoring in the proliferation risks of both technologies.
- Increase funding for safeguards research.
- Promote safe and secure storage of spent fuel until the time when reprocessing may become economically attractive.
- Evaluate multiple sites for permanent waste repositories based on political fairness and sound scientific assessments. Obtain buy-in from the public and local governments.
- Use secure interim spent fuel storage employing dry storage casks to relieve build up on spent fuel pools.
- Provide fuel leasing services that would include take back of spent fuel to either the fuel supplier state or a third party.
- Develop regional spent fuel storage facilities.
- Obtain better estimates on the remaining global reserves of uranium.
- Provide research support for developing more efficient nuclear power plants that would produce more electrical power per thermal power than today's

fleet of reactors. Similarly, research more effective ways to make more efficient use of uranium fuel and reduce the amounts of plutonium-239 produced.

### BIOGRAPHY FOR CHARLES D. FERGUSON

Dr. Charles D. Ferguson is the Philip D. Reed senior fellow for science and technology at the Council on Foreign Relations (CFR). He is also an adjunct professor in the security studies program at Georgetown University, where he teaches a graduate-level course titled "Nuclear Technologies and Security," and an adjunct lecturer in the national security studies program at the Johns Hopkins University, where he teaches a graduate-level course titled "Weapons of Mass Destruction Technologies." His areas of expertise include arms control, climate change, energy policy, and nuclear and radiological terrorism. At CFR, he specializes in analyzing nuclear energy, nuclear nonproliferation, and the prevention of nuclear terrorism. He has written the Council Special Report *Nuclear Energy: Balancing Benefits and Risks,* published in April 2007. Most recently, he served as the project director for the CFR-sponsored Independent Task Force on U.S. Nuclear Weapons Policy, chaired by William Perry and Brent Scowcroft. The task force report was published in April 2009.

Prior to arriving at CFR in September 2004, Dr. Ferguson worked as the scientist-in-residence at the Monterey Institute's Center for Nonproliferation Studies (CNS). At CNS, he co-authored (with William Potter) the book *The Four Faces of Nuclear Terrorism* (Routledge, 2005). He was also the lead author of the award-winning report *Commercial Radioactive Sources: Surveying the Security Risks,* which was published in January 2003 and was one of the first post-9/11 reports to assess the radiological dispersal device, or "dirty bomb," threat. This report won the 2003 Robert S. Landauer Lecture Award from the Health Physics Society.

Dr. Ferguson has consulted with the International Atomic Energy Agency, the Los Alamos National Laboratory, Sandia National Laboratories and the National Nuclear Security Administration. He served as a physical scientist in the Office of the Senior Coordinator for Nuclear Safety at the U.S. Department of State, where he helped develop U.S. Government policies on nuclear safety and security issues. He has also worked on nuclear proliferation and arms control issues as a senior research analyst and director of the nuclear policy project at the Federation of American Scientists.

After graduating with distinction from the United States Naval Academy, he served as an officer on a fleet ballistic missile submarine and studied nuclear engineering at the Naval Nuclear Power School. Dr. Ferguson has written numerous articles on energy policy, missile defense, nuclear arms control, nuclear energy, nuclear proliferation, and nuclear terrorism. These publications have appeared in the *Bulletin of the Atomic Scientists,* the *Christian Science Monitor, Issues in Science and Technology,* the *International Herald Tribune,* the *Los Angeles Times,* the *National Interest* online, the *Wall Street Journal,* and the *Washington Post.* He has also authored or co-authored several peer-reviewed scientific articles and published in top physics journals. He holds a Ph.D. in physics from Boston University.

## DISCUSSION

Chairman GORDON. Thank you. There were lots of good points made. The survey of the available uranium really is something we should try to do.

## DISCOURAGING WEAPONS PROLIFERATION IN NUCLEAR PROCESSING

Well, first let me thank the witnesses for speaking in English. I was a little concerned that some of us wouldn't understand what you were talking about but you dumbed it down for us, and I thank you for that. I would like to also ask if you would submit to the Committee your suggestions for an R&D roadmap. I know it was somewhat mentioned but I would like what we should be recommending to the Department of Energy, and while you are doing that, what you think should be the federal role versus the private role, and before I get into my question that I posed earlier, I would like to not start a fist fight but I would like to see whether there is anyone who disagrees with Dr. Hanson's, you know, very specific statement that there is no such thing or will be no such thing as a proliferation-proof reprocessing. Does anyone disagree with that? Okay, Ms. Price.

Ms. PRICE. I guess what I would say to put it into context is the question, and I think Dr. Ferguson touched on it, is how you safeguard the treatment of plutonium through the process. And I would submit that the sodium-cooled reactor with the electro-metallurgical processing doesn't separate plutonium. All of the transuranics are burned in the reactor, and that is one way to help safeguard. Now, an absolute statement that there is no absolutely no chance may be an impossible standard, but it is not the same type of concern, if you will, if the plutonium is not separated out on its own and there are other methods where in fact it is consumed without that separation feature.

Chairman GORDON. Yes, sir.

Dr. FERGUSON. Mr. Chairman, very briefly. I think it was four years ago in 2005 that the American Physical Society—and Dr. Ehlers and I are members of APS—they published a study on safeguard challenges and they recommended we devote more to R&D on safeguards, and they clearly stated in the beginning of the report there is no such thing as proliferation-proof technologies. These things are dual use. You can make them ever more proliferation resistant if we are willing to spend the resources to do it.

Chairman GORDON. So it can be significantly reduced. Would that be fair to say, but not eliminated?

Dr. FERGUSON. Yes, sir. That is true. We can't eliminate them.

## EXISTING VERSUS NEXT GENERATION TECHNOLOGIES

Chairman GORDON. Okay. So let us get back to my earlier question. In terms of something we should be doing in this country, do we move forward with existing reprocessing technologies or should we wait for that next generation, and do we have the storage capacity to wait, which is somewhat—how long does it take us to get there, and the cost differentials. Who would like to start with that? Yes, sir.

Dr. PETERS. I can start.

Chairman GORDON. Dr. Peters.

Dr. PETERS. So as I said in my opening statement, I don't think we should proceed with existing technologies, and let me expand on why I think that. The DOE program over the course of the last 10 years has done a lot of analysis, systems analysis, I will call it, of the fuel cycle and thinking about whether we should go with recycling in LWRs or bypass that and go directly to fast reactors. So we have looked at the options, and in the end I am going to tell you that we need to continue to evaluate the options, but as we have done that we have seen there is some benefit, as Alan alluded to, with going to existing technologies and recycling and thermal reactors. You get volume reduction. You do get reduction in some of the radiotoxic constituents as well as the heat-generating radionuclides. But it is only part of the way there, and if you want to go to the full benefit you need to go to full closure of the fuel cycle. And even the countries that are currently doing like France, Japan, Russia that are currently practicing aqueous reprocessing using PUREX-like technologies and perhaps recycling and thermal reactors, ultimately their plan is to go to fast reactors and full closure of the fuel cycle. So the question really on the table is, do we leapfrog or do we take a more evolutionary path? And I would put to you that because we have not currently put significant investment in the United States that we should seriously consider the leapfrog approach, meaning that we develop advanced technologies as we do that in the lab. We have done a lot of that in the lab already, do some additional science-based work, demonstrate those at a reasonable engineering scale and then go build them at the commercial scale.

One other point I will make about storage, so the current spent fuel inventory is stored, spread across multiple sites. One hundred and twenty-one sites, 39 states have currently stored spent fuel at reactor sites. I won't get into whether it is better to have centralized storage or storage at different sites but it is safe and secure as it sits right now. It is not a permanent solution, so we need to move in a measured path.

Chairman GORDON. I don't have much time left, so is there anyone else that wants to address that? I thought you probably would, Dr. Hanson.

Dr. HANSON. We have at Areva over 40 years of research built into our existing processes and we have developed a future process we call COEX, which does not separate out pure plutonium. It is a step in the right direction.

With regard to the leapfrog or evolution, I would like to use an analogy. We are embarking on a nuclear renaissance, and the reactors that are being built around the world and are going to be built in the United States are called Generation Three Plus. They are evolutionary reactors. I cannot find a single utility anywhere in the world that is prepared to leapfrog to a fast reactor today. The situation is identical with recycling. We have evolutionary technologies which we can use today and we need to research a lot more before we can do the leapfrog. The problem with leaping is you don't know where you are going to land, and instead of landing on the lily pad you may end up in the water and drown because your technology doesn't survive.

Chairman GORDON. I don't want to abuse my time, so do you want to have a rebuttal there, Ms. Price?

Ms. PRICE. I guess I would echo Dr. Peters' comments first and the money that we would have to invest to build the infrastructure for reprocessing could be better spent in working on the technology roadmap for developing the recycling. The roadmap that we developed, and this has been developed in conjunction with many of the national labs, would say that you could develop recycling over the course of 15 to 20 years, and there is programmatic research that is laid out there.

One of the big advantages we haven't talked about but Dr. Ferguson mentioned on the uranium supply balance is, recycling, full recycling allows you to extract about 90 percent of the available energy that is inherent in uranium and reduce the waste volumes by about 98 percent, so not only are you having a better overall conservation with respect to an important natural resource, you have got completely different characteristics that you can then consider in evaluating your long-term storage.

TIME FRAMES FOR STORAGE AND RECYCLING

Chairman GORDON. Thank you. You know, one of the unfortunate things about this format is that we don't get to go deeper, and we have some roundtables, and I think we will probably have more of these, where we can really talk. So just in conclusion, very quickly, I want each of you to give me two numbers. The first number is how do you think that we can continue to store at existing locations with dry casks wherever it might be, and the second is, how long do you think it would take to get that next generation recycling? Dr. Peters, just two numbers real quickly across everybody.

Dr. PETERS. We can store until the end of the century if you want to but I would argue commercial by 2050.

Chairman GORDON. Dr. Hanson?

Dr. HANSON. We can continue to store virtually indefinitely. It is safe and secure and there are no restrictions on the ability to supply storage, so that is not a concern.

Chairman GORDON. On site. I am talking about on site.

Dr. HANSON. On site, yes, even on site. I wouldn't recommend doing that but nonetheless it is possible. Your second request with regard to the number of years, to do a change in the nuclear industry, 40 years——

Chairman GORDON. Just two numbers. We just need two numbers.

Dr. HANSON. Forty years.

Chairman GORDON. Okay. Ms. Price?

Ms. PRICE. There is sufficient capacity on the nuclear sites to store them for as long as the nuclear plants are running, so I don't have any issues with that. And I would say 15 to 20 years and you can have a sodium-cooled reactor in service.

Chairman GORDON. And——

Dr. FERGUSON. And I echo Dr. Peters' comments. I think end of the century on site with dry cask storage and you can probably get this up and running mid century in terms of commercial processes if we need to.

Chairman GORDON. Thank you for your indulgence. Dr. Ehlers is recognized.

THE MERITS OF DIFFERENT REACTOR TYPES

Mr. EHLERS. Thank you, Mr. Chairman.

First of all, we will go to you, Ms. Price. You talked about sodium-cooled reactors, and I have just been out of the field for too long. Where does that stand now? The last time I looked at it, they didn't look very promising. What has developed there? Are they going to be available commercially? Are they really an answer or not?

Ms. PRICE. Well, to start off, as you know, the sodium-cooled reactor has been around since the 1950s. More recently in about 1983, we began developing a sodium-cooled reactor and it, in fact, continued with development with government funding through the

Advanced Liquid Metal Reactor Program that was funded through 1995, and so in fact there have been quite a few developments in the fast reactor technology since the early 1950s when it was first introduced. At that time in between the 1995 and the 2001 time frame, the NRC actually reviewed the conceptual design work for the advanced—for the sodium-cooled reactor and found that there were no significant safety concerns that would prevent moving ahead to taking the next step. There is still quite a bit of research and development work and demonstration work to be done, but we believe that the proof of concept is there and that in fact the reactor with the development path would be successful.

Mr. EHLERS. You also mentioned water-moderated reactors and that they are both functional and not detrimental to the other. They improve the total fuel cycle. I am just curious, are there certain areas of our country or certain areas of the world that are better for either or both of these reactors or are they universally applicable?

Ms. PRICE. The way we sort of think about it is like the analogy, to borrow from my testimony, of oil and how do you extract all of the value in a barrel of oil. A lot of the oil is going to be used to fund the gasoline engine but there is going to be some oil that is going to be used to make diesel for use in diesel cars, and the question is, which is better, an internal combustion engine or a diesel engine? And the answer is, they have their own applicability and so there are going to be situations where they are very complementary to each other and they are not at all substitutes. What I would say in the context of an overall nuclear balance is that the view of using a fast reactor to address the transuranics would require about a third of your nuclear installed base, 30 percent of the megawatts that you would generate via fast reactor and the balance of it be a light water reactor and that would be sort of a system that would be in balance. All of the transuranics and all of the waste product in the used fuel then could be sent over to the fast reactor and then you would not be building up any more spent fuel.

Mr. EHLERS. Okay. Thank you.

## FUEL REPROCESSING COSTS

Dr. Hanson, in Dr. Ferguson's testimony he states that most countries have not chosen the reprocessing route because of the significantly greater fuel cost. That doesn't seem quite to jive with what you said. What do you think about that statement, or what is your reaction?

Dr. HANSON. Our experience in Europe is that the additional cost for doing recycling approximates five to six percent of the costs of producing electricity. It is not a large amount. I don't think people have foregone recycling because of the cost issue. You need to have a fairly significant, sizable industry in order to justify doing recycling. If you have a small situation with only a few reactors, it is very hard to justify it. And most countries are not going to be prepared to make the massive up-front investment in building a facility as long as they can provide the service from somebody else like Areva or some day, the United States.

Mr. EHLERS. Are you suggesting that Areva or someone else would provide the service in various parts of the world and all the waste would be shipped to those areas?

Dr. HANSON. That is in fact what we are doing today. We are doing recycling for Japan, for Switzerland, for Belgium, a number of other countries, Italy now, and we provide the service. We either return the plutonium to them as MOX fuel or else we give it to another reactor, and only the high-level waste goes back to the country from which the fuel came.

Mr. EHLERS. And are you encountering any problems from people who are objecting to a plant being in the area or waste being transported through their particular country or their part of the country?

Dr. HANSON. The only place where that has been presented a significant problem has been in Germany, where the step away from nuclear and the Green Party has made it a big issue, and they have tried to impede transports, but the transports are continuing as we speak, mainly of returning waste today.

Mr. EHLERS. Thank you. Thank you very much. I yield back.

Chairman GORDON. Thank you, Dr. Ehlers, right on time, and the prompt Ms. Brooks is recognized, or did she—Ms. Edwards. I'm sorry. There she is. Ms. Edwards.

Ms. EDWARDS. Thank you, Mr. Chairman, and you know, when you were asking earlier, Mr. Chairman, whether there were any folks who might disagree, I thought you were talking about up here on the panel.

## MORE PROLIFERATION CONCERNS

I want to ask you a couple of questions, and one has to do with a letter, and I don't know if you are aware of it, that was sent to President Obama in December from about 35 organizations from around this country raising serious concerns about both reprocessing and recycling, and in particular they point to the reprocessing that is done in France, the U.K., Japan and Russia, 250 metric tons of separated plutonium, which they say is enough to make about 30,000 nuclear weapons. And according to a GAO report in 2008, reprocessing irradiated fuel would pose a greater risk of proliferation in comparison with direct disposal in a geologic repository, and so I wonder if you have some of those same concerns. And I understand that the Council on Foreign Relations has raised exactly that concern, and yet Dr. Hanson, I think that you have dismissed that as both a proliferation concern and a security concern.

Dr. HANSON. I think that question is directed to me. I would like to go back to what I said in my testimony. Areva does not believe nor do I personally believe, I don't think anybody on this panel believes that we ought to have reprocessing and recycling taking place in every country on the face of the Earth. This would not be a good thing to do. However, the proliferation risk if we do it in the United States is vanishingly small, vanishingly small. If we can protect all of the nuclear weapons and all the nuclear material we have in this country, then we can easily protect the material that would be in commerce from doing recycling. So I don't think it is a risk in the United States at all. Around the world in other places, yes, it could be a risk.

Ms. EDWARDS. And is Areva interested in building a reprocessing plant here in the United States?

Dr. HANSON. At the Carnegie Endowment conference held earlier this year, our Chairwoman, Anne Lauvergeon, made a statement to that nonproliferation conference. She said there were only two countries in the world to which Areva would be prepared to export our technology. One of them is the United States and the second one is China.

FINANCIAL COSTS

Ms. EDWARDS. Thank you. And then to any of our other panelists, some concerns have been raised by the Union of Concerned Scientists with regard to reprocessing spent nuclear waste, and among them they cite an increased volume of radioactive waste by a factor of seven, significantly increased by more than a factor of six the volume of low-level waste requiring disposal in a licensed low-level waste facility, and a great increase by a factor of 160 in the volume of greater than class C low-level waste which contains significant amounts of long-lived and highly radiotoxic isotopes such as plutonium and americium. There is no U.S. facility currently as we know licensed to accept this waste. And they also cite the reduction in the volume of high-level waste requiring disposal in a deep geologic repository which we also don't have, less than 25 percent. And so I guess my question is, is the investment that we are talking about, literally hundreds of billions of dollars that would be required for reprocessing, given the security questions, given the lack of a geologic repository for the fuel, is this really worth our investment or should we be making more investments particularly in sources of energy that actually are going to get us someplace else without the attendant costs? I will just leave that open to the panel.

Dr. PETERS. Well, I guess first I would say it seems to me like we need to be investing in a lot of different energy sources, but to me nuclear is inescapable in terms of contribution to baseload. I will say that first. Second, as you well know, to the comments by Union of Concerned Scientists, all the waste that they are referring to exists. We have to deal with greater than class C low-level waste and high-level waste already. Is there increase—the high-level waste volume reduction is actually a bit more than significant than they say, and I think Alan alluded to that in his testimony. There would be an increase in low-level waste, small increase, and also probably a small increase in greater than class C, but it is a tradeoff, and I would argue when you put all this together and think about sustainability, reducing the overall burden on high-level waste, which is the most toxic, and all the other components, particularly in an era where we are hoping nuclear will grow, it makes sense to go to recycling because we are going to have to develop the sites anyway. The nice thing about recycling also is you can tailor the waste streams and perhaps look at different disposal settings for the different waste streams, which is much different than the way we think about the problem right now.

Ms. EDWARDS. Thank you. My time has expired, and I probably will have some questions——

Chairman GORDON. Well, I think Dr. Ferguson wants to probably——

Ms. EDWARDS. Thank you.

Chairman GORDON. Let Dr. Ferguson finish.

Dr. FERGUSON. Thank you, Congresswoman Edwards, for raising those important points. And if we look at what Ms. Price said about the number of fast reactors we would need under closing the fuel cycle scheme that would really burn up these heavier elements, these transuranic elements to really reduce the burden on a nuclear waste repository, it is basically a 2:1 ratio so you need basically one fast reactor for every two light water reactors you have. So we have 104 light water reactors right now in the United States. If we just keep that constant, which I think all four of us—one point is that it is not a question about being for or against nuclear power. All four of us on the panel are for nuclear energy, and I think we all want to see it continue to grow. But let us assume we have roughly 100 light water reactors. We will need 50 fast reactors. How much are they going to cost? And they cost a lot more than a light water reactor. What we really need to hear from—it would have been great if we had a fifth panelist from the utility company and ask that person whether they would be willing to invest in a fast reactor. We are having a hard enough time in this country getting utilities to invest in light water reactors that get the next generation of nuclear reactors being built in this country and here we are trying to think about something that is maybe 50 years in the future.

Chairman GORDON. Thank you, Dr. Ferguson. There are very serious issues that go along with nuclear power, and I think this committee, the diversity of thought is going to help us get there better and so keep up the good work. We need you, Ms. Edwards and Ms. Woolsey, to ask the tough questions so that we can get better thoughts.

And speaking of diversity, we recognize Mr. Rohrabacher.

## HIGH-TEMPERATURE GAS-COOLED REACTORS

Mr. ROHRABACHER. And this may fit right in with the comments on our alternative reactors in terms of the traditional reactors that we have been dealing with and the fast reactors that you just mentioned. But back to the letter that I submitted for the record, just for the sake of my colleagues, it is a letter that I received from Nikolay—sorry about mispronouncing the name—Stepnoy from Kurchatov Institute in Moscow, and I would like to read a portion of that letter *[see Appendix: Additional Material for the Record]* at this time and then follow up with a couple questions that I have for the panel. This is addressed to me: "Dear Congressman: It is time to upgrade the relations between the United States and Russia, particularly in the area of nuclear power. It is time to move from a relationship where the U.S. provides technical assistance to Russia to a real partnership for improving global energy and economic, environment and nonproliferation. I believe that the best developed and most fruitful area where the United States and Russia can perform nuclear cooperation is in the joint development of a high-temperature gas-cooled reactor. The United States and Russia must work together to not only bring the benefits of this reactor to both our countries but to provide this same proliferation-resistant and secure type of reactor to other less-developed countries who are moving quickly to harness the benefits of nuclear energy. In this way we can make great progress in nonproliferation economic development without harming our environment."

Let me just note that if 20 years ago one would think that I was reading a letter about cooperation with Russia in this area, I would tell you you were nuts. But the fact is, I think today some of the greatest, the most important avenue we have to succeed in some of the issues that are being discussed here today is our cooperation with other countries in particular with the former Soviet Union, with Russia, who is reaching out to us for this type of cooperation. Now, with that said, the letter mentions the high-temperature gas-cooled reactor. I would like to ask the panel if that is a technology that would significantly reduce the waste that has to be dealt with in the recycling and reprocessing process that is being discussed today. I am not sure what the panel knows about the high-temperature gas-cooled reactor but if—yes, sir.

Dr. FERGUSON. Well, I heartily endorse your comments about a U.S.-Russia cooperation, and just to briefly plug something I recently directed, the Council on Foreign Relations task force report on nuclear weapons policy, chaired by Brent Scowcroft and Bill Perry, and I was the Project Director, we just published it a couple of weeks ago and we have made a recommendation in there that we need greater cooperation with Russia on peaceful nuclear energy. The particular point you make about high-temperature gas reactors I think is an important one. The Department of Energy itself has looked at these reactors—not enough, in my opinion—but what they have seen is that there are some benefits to be derived from them, maybe not a huge benefit in terms of waste reduction, but one benefit is that if they are more efficient, then you can get a lot more electrical energy produced for the amount of heat you produce from nuclear fission. If we had to do it all over again, you know, go back 50 years into the past, 1950s when we started commercial nuclear power, it probably would have been a wise decision to have stronger development of these type of reactors. Right now the light water reactors are getting about a third efficiency so we are wasting about two-thirds of the energy. With the HTGR, you can get about 45 percent or so efficiency out of these, so that is one thing that——

Mr. ROHRABACHER. So more efficiency, you actually have less waste to have to deal with.

Dr. FERGUSON. Less waste to deal with, and in terms of the proliferation risk, if you look at the plutonium 239 content coming out, the isotope that is a proliferation concern, it is actually a lower percentage ratio than you would see from a light water reactor, depending on how those reactors typically operate.

Mr. ROHRABACHER. Mr. Chairman, I would just draw attention to that testimony, and this is an issue we should be pushing our experts to look at as an alternative if it provides those kind of benefits. Any other reaction from the panel?

Dr. PETERS. Let me say, so the high-temperature gas reactor is one of the concepts, as Dr. Ferguson alluded to, that is part of the Gen IV international forum, so we are looking at it. General

Atomics, which is a U.S.-based company, has been thinking a lot about the high-temperature gas reactor, and so there is a lot of thinking about it. As far as international cooperation, I can't agree more, especially in R&D.

Mr. ROHRABACHER. One last note before—we have the person, the scientist who wrote me that letter from Russia, with us today, and his nickname is Nick Nick, and I wonder if we could just say hello. Thank you very much for indulging me, Mr. Chairman.

Chairman GORDON. Welcome, Dr. Nick Nick, and I have to say that listening to Mr. Rohrabacher advocate cooperation with Russia makes me feel much better about our success in the Middle East.

Mr. BAIRD. Mr. Chairman, on that point, we want to point out that it is not just the icecaps that are melting off.

Chairman GORDON. Mr. Luján is recognized for five minutes.

Mr. LUJÁN. Mr. Chairman, thank you very much. Thank you, Chairman Baird. Mr. Chairman, I am pleased today that we are here today talking about this because as the debate continues about the future of energy generation in our country and the role that nuclear power has, it is critical that we as a nation invest in the necessary research and development to talk about the waste, to talk about what needs to be done with spent fuel and how we can break it down, how we as a nation have fallen behind other nations and how simply sticking it in the ground without attempting to break it down or attempting to solve this problem is blissful ignorance. And I am really happy that we are here today to talk about this and, Mr. Chairman, to really be excited about the fact that in the hearing charter today that there is widespread agreement that a more robust long-term research and development program is needed to address these outstanding issues and to truly look to see how we can focus a lot of our energy and investment leaning upon the expertise that we have around the country, around the world, to help accelerate this, and to have the distinguished panelists that we have today that have expertise in each of these areas is something that is real important to me.

### COSTS OF NUCLEAR WASTE MANAGEMENT TODAY

Mr. Chairman, I would be anxious to hear from Ms. Price. Do you think that the way that we are handling waste today is adequate or can we be doing it better?

Ms. PRICE. Well, I think in terms of the way the utilities handle it today, it is very safely stored and appropriately stored in the utility sites either in pools or in dry cask storage, and so I think we all four agreed that there is sufficient ability to store it at the utility sites today. Does that mean that we need to not look ahead to the fact that we really do need to have some sort of repository and the nature of the repository and the size and the characteristics of it are dependent upon what solution we choose for managing the waste? So today, are we fine? Yes. Can new plants be built with sufficient capacity on their sites to be able to handle the used nuclear fuel when it comes out of the reactors? Yes. But we do need to be looking ahead to a long-term solution that is going to help us address and really maximize the value of what is an asset that we have in used nuclear fuel.

Mr. LUJÁN. Ms. Price, is utilizing the repository, simply storing it, less expensive than recycling it?

Ms. PRICE. It is not clear that it is going to be less expensive in the long run because the characteristics of the repository could be quite different. If you have to isolate the fuel for hundreds of thousands of years, you have different considerations than if you have to isolate it for thousands or hundreds of years. And so if you can isolate and store the fuel for hundreds of years and then have the heat reduction, the radiotoxicity reduced to a level where it is no longer considered high-level waste, then you have got different characteristics and you might be able to utilize the repository in a different fashion. So the cost of the repository and the management of that over the long run compared to the cost for the recycling program is something that needs to be evaluated.

Mr. LUJÁN. Then why aren't we recycling today and we are just talking about storing it?

Ms. PRICE. Recycling is one of those things that is, as far as I know from a history standpoint, was not considered, or we didn't move ahead with it in sort of the late 1970s, early 1980s.

Mr. LUJÁN. Could the argument be made that it is cheaper, less expensive to store in a facility like Yucca Mountain as opposed to engaging in the necessary means to be able to invest in the technology to adequately break down to be able to utilize recycled spent fuel or waste?

Ms. PRICE. My last comment, and I will turn it over to my colleagues on the panel, I would say that that wasn't the decision that drove storing it on site in a repository solution versus recycling opportunities. That was driven by other factors including proliferation concerns and risks at the time, and I think this is the time to look at—if we are going to move ahead with the nuclear renaissance, we need to have an all-enclosed fuel cycle opportunity that really allows us to safely manage nuclear fuel in a more safe, more secure way going forward.

Mr. LUJÁN. Thank you.

## THE NAVAJO NATION'S URANIUM SUPPLY

If I could, Dr. Ferguson, you mentioned the MIT study that is taking into consideration how much uranium is out there and the inventories. Are you aware if the Navajo Nation's uranium supply was included in the MIT study?

Dr. FERGUSON. No, I am not, but that is an important question, you know, how does uranium mining, prospecting affect certain groups of people, and I know this has been a big environmental concern with that group of people.

Mr. LUJÁN. And Mr. Chairman, the reason I bring that question up is, as we look towards the debate about how, the role nuclear energy will have in the future of our nation's energy needs, that we not forget about many of the abandoned uranium mines around the country, at current count, over 500 in the Navajo Nation alone, that need to be addressed as we talk about this as well. And so as we talk about the importance of recycling and R&D to being able to break down waste that we not forget about some of the responsibilities that we have also with some of the abandoned mines and the people that are being impacted. To date, there have been 113 structures that are in process of being demolished, 27 radiation-contaminated structures and 10 residential yards. People are living in these contaminated areas, and I think that we need to make sure that we talk about that at some point as well.

Thank you very much, Mr. Chairman, for this important hearing.

Chairman GORDON. Thank you for bringing that up. Again, I think one of the things we have learned today is that we do need to again have that type of survey. We need to be reviewing the things you just talked about. We will have—you know, this kind of discussion is not off limits to this committee and again, there are hard questions that need to be asked too and we will try to do that.

Ms. Biggert, you are recognized for five minutes.

Ms. BIGGERT. Thank you so much, Mr. Chairman, and thank you all for being here. This is, I think, a really good hearing.

GNEP AND THE ADVANCED FUEL CYCLE INITIATIVE

About 11 years ago when I first came here and the first month that I was here, I got a call that the President had cut $20 million from the electro-metallurgical program at Argonne. I didn't even know how to pronounce it at the time but I was very concerned and worked to get that money back, so this is how long, at least when I have been here, that we really have been working on reprocessing and now we are talking recycling but it is very frustrating, I think, that we really haven't moved the goal posts very far, and in fact there were six reprocessing plants that were built in this country and one opened and then the rest were shut down without even opening by President Carter and still we sit, you know, waiting for something to happen.

I know, Dr. Peters, you said that you don't think that it is really urgent that we move ahead right now but I am frustrated that we are not making enough progress, and particularly if we are going to face something like cap and trade and, you know, all the things that we are going to have to do because of the carbon, you know, because of the carbon issue and I think that is very important, but I think that nuclear really has to be at the forefront of moving ahead if we are going to be able to have—reduce the carbon in this country and reprocessing, recycling, I guess we are calling it recycling now, is so important but we have to move ahead, and I think the research and development and the demonstration is so important. When we had GNEP in the last few years, we have talked about what that means, and I would like to ask Dr. Peters, what are the—what research aspects of GNEP and the advanced fuel cycle initiative, which of those, or what aspects of those should be continued?

Dr. PETERS. So what should continue is, we should continue to develop advanced reprocessing technologies both aqueous and electro-metallurgical, electrochemical, pyro, whatever you want to call it at the lab scale for sure. That is work that, as you are aware, has been going on for a decade or more. There also needs to continue to be work on advanced fuels, developing advanced fuels for ultimate recycling. There needs to be work on the waste management aspects of the problem, so other concepts, say, in addition to say, Yucca Mountain repository, thinking about certain streams going down bore holes versus salt disposal versus alternative disposal concepts, all this has to be brought together through a very robust analysis of the overall system so that you think about the economics, the nonproliferation and all that. So the advanced fuel cycle initiative program that existed before GNEP really is where we are going back to quite frankly, but the component that we need to add to it is the demonstration component, and that gets back to needing to think very carefully over the long-term about the R&D needs for the science and engineering at the lab scale but thinking about ultimately going to demonstration, and that needs to be laid out.

### TIME ISSUES AND MOX FUEL

Ms. BIGGERT. I think the problem that we had with the GNEP was that there was—some wanted to move right from the research and development to the commercialization rather than doing the demonstration or the system analysis but how long is this going to take? And Dr. Hanson, you talked about—and I have been to France to see what you do there, and it seems like you are moving and everyone talks about the proliferation and yet I think we were so worried about that 30 years ago and yet most of the—and unfortunately, most of the countries that we worried about already have some capabilities in that area, so we need to move ahead faster to find, you know, maybe something resistant but at least to go forward on our own with our development. I guess the MOX facility that is being built at Savannah River site is scheduled to produce MOX fuel by 2016. Who will be using this MOX fuel that is being developed?

Dr. HANSON. To your question with regard to who will use the MOX fuel, it will be any of the U.S. utilities who choose to purchase this fuel from the MOX project. At the moment there are discussions ongoing with three or four U.S. utilities who have a strong interest in purchasing that material for their reactors.

Ms. BIGGERT. Do you think we are moving fast enough for development of the——

Dr. HANSON. No, absolutely not. We are sitting now on 60,000 metric tons of spent fuel. We are discharging 2,000 every single year, and that is before we build any new reactors. If it takes us 20 years to start up recycling, we will have 100,000 metric tons of fuel in storage. The largest plant in the world, which we operate in France, reprocesses and recycles about 1,700 metric tons a year. That means if we replicated that plant in the United States, it will take 60 years just to get rid of the inventory without touching the material that is being discharged. I think we have waited too long. I think we need to start as soon as we can while continuing the R&D on advanced technologies to do it even more efficiently, and I applaud the Committee's support of the AFCI program in that regard. I think that is very, very important. But I don't think we can wait for revolutionary changes which may never actually come to fruition.

Ms. BIGGERT. Thank you. I yield back.

Chairman GORDON. Ms. Kosmas is recognized for five minutes.

## Clarification on Reprocessing, Recycling, and Fast Reactors

Ms. KOSMAS. Thank you, Mr. Chairman. I appreciate this opportunity and I thank you all for being here and I appreciate that the Chairman said this had been dumbed down to us, but I think I need to go one level lower for the technological part of it. But in terms of our—I state for the record that I am a proponent of nuclear energy as one of the alternative supplies that we need in order to move forward, and so I very much am interested and enlightened by what you have said, what I was able to grasp from it. Perhaps my comment would be that I think we all—you all said that the recognizable problems are nonproliferation, cost and waste, and those are things that would have to be considered no matter what course of action we took. As I understood you, Dr. Peters said fast track the advanced fuel cycle program. Dr. Hanson said recycle and bring it home, and if I understood correctly, Dr. Price said we could be doing both. Did you say that is possible to create a situation in which 70 percent is based on recycling and 30 percent uses the recycled, or did I misunderstand you?

Ms. PRICE. I would like to clarify that a little bit. Dr. Hanson and I advocate different ways to handle the used nuclear fuel. The technique he uses in reprocessing does extract some of the incremental energy and burns the plutonium. The technology that I am advocating actually burns up all of the high heat-bearing constituents in the used nuclear fuel and so it is a different technology. I do think we should continue to do research, as Dr. Peters suggests, focused on the recycling side of things because I think we can drive that and have a better all-in solution in the back end.

Ms. KOSMAS. Thank you. I think that was clarified, but I appreciate it very much.

So Dr. Peters, if you are recommending that the United States advanced cycle program develop a roadmap, in your opinion, what is the reasonable timetable and the budget for the development of that roadmap? In other words, where should we be going now, and would you agree that continuing the recycling while working on the advanced is a good parallel track?

Dr. PETERS. So first on the roadmap, to cost estimate on the fly here, I am not speaking for the Department, but we wouldn't reinvent the wheel. There has been a tremendous amount of work done already. That is the first thing. So I am imagining a group of lab, university and industry people getting together over the course of the next six months to a year that could put together, I think, a very robust roadmap, you know. It would not be—it would not break the bank. It would be, you know, a few million dollars kind of thing, because we have thought about this very deeply. I think we just need to come together and lay out the right path forward.

Your other question, should we—what I was trying—I think you articulated my position correctly in your introductory remarks. I think we should continue the advanced fuel cycle program but I would argue for a bump in the investment once we have the right roadmap, and I think the outcome of that road-mapping exercise ultimately is going to be a policy decision to leapfrog, I hope.

Ms. KOSMAS. Okay. Dr. Hanson, would you restate what I thought I heard you say about the leapfrog?

Dr. HANSON. Yes. In my long career in the nuclear industry, I have never seen a leapfrog that was successful in this industry. I started in the fast reactor world when I got out of school and it was just around the corner and we were going to be turning out fast reactors and they were going to replace light water reactors. The fast reactor is a little bit like fusion. It is always 20, 30 years into the future and it just keeps on receding there. I would like to have the optimism that Dr. Price has with regard to fast reactors but my own experience is that they are not yet proven to be commercially acceptable. We are only having a nuclear renaissance because the utilities have driven capacity factors in excess of 90 percent and they are running the plants very efficiently. There is not a single fast reactor anywhere in the world that has even achieved a 50 percent capacity factor. There is a lot of proof of principle which needs to be done before any utility will purchase a fast reactor. So if we are talking about leapfrogging, that leap may take us a very, very long time before we land.

Ms. KOSMAS. Thank you very much.

Then Dr. Ferguson, would you reiterate what you said about the utilities needing to be at the table?

Dr. FERGUSON. Absolutely, and I think on the fast reactor question, I think to narrow down a specific question relevant to your committee is, what is the role of the U.S. Government. Should you be putting money into developing a demonstration project for a fast reactor? I know there has been a big debate in a related area that is a demo capture, carbon capture and storage from coal-fired plants. We have been back and forth on this and it looks like Secretary Chu is now willing to put about a billion dollars toward that. In my opinion, it is a step in the right direction.

So the question comes, and I think Dr. Hanson has framed it in an interesting way. We have looked at France, we look at Japan, we even look at Russia and we look at India, the few countries that have some experience with fast reactors. When I was in France just two months ago, I spent a week there touring, and I visited the Phoenix reactor site. They are shutting it down this year. I talked to the director. He is a very sad man because they are shutting it down all the time and it is, you know, uncertain when France is even going to get its next fast reactor built, maybe 2020 or beyond. So that is part of—to fully close the fuel cycle. That is what Ms. Price is saying. Basically you have two choices here. You would have the choice of what the French are doing now, which is a once-through recycle, and they are storing the MOX spent nuclear fuel so they still have to pay for those storage costs and the view is that they are going to eventually mine that plutonium and that spent fuel to feed fast reactors in the future, but we don't know if these fast reactors are going to work or not or whether they are economically feasible. Maybe it does make sense to put some federal money into one demonstration project and see if this works or not.

Chairman GORDON. Thank you, Dr. Ferguson.

Ms. Kosmas, your questions certainly demonstrate that we need to dig more and learn more about this. Thank you.

Ms. KOSMAS. Thank you, Mr. Chairman. I look forward to the roundtable discussion. Thank you.

Chairman GORDON. Mr. Bilbray is recognized for five minutes.

Mr. BILBRAY. Thank you, Mr. Chairman. You know, Mr. Chairman, I would like to stop a second and really congratulate you at having this hearing, and I just want to say that I appreciate the fact that you have been brave enough to openly discuss these issues. Political orthodoxy basically says there is a lot of discussion that this committee has been doing that shouldn't be done if you want to, you know, be a political might in American politics, but just having this discussion really I think does credit to this committee and shows how essential this committee is to not just Congress but this nation, and so I just really want to congratulate you on that because the fact is that when it comes to anything nuclear, we have seen prejudice and ignorance stand in the way of science and just as much as history has damned people in the past for allowing their prejudices and their phobias to stand in the way of intellectual decision and discussion, I think that time is going to show that you led the charge on opening the door, pulling the curtain back and being frankly looking at the facts rather than misperceptions of the past.

Chairman GORDON. Thank you, Mr. Bilbray, and your time has extended another 10 minutes.

Mr. EHLERS. I think he is going nuclear.

NUCLEAR MATERIALS TRANSPORT

Mr. BILBRAY. It is not a melt-down. Look, my question is, one of the things—we will get into this. One of the great obstructions of working at—first of all, I totally agree that we ought to be looking not at disposal but at storage based on either short-term or long-term reprocessing in some way, and we can talk about that. But let us be frank about it. One of the great oppositions to the Yucca Mountain project was not based on on-site location issues, it was based on transport. Now, how in the world will we be able to face the political heat, and I know you are probably the wrong ones, but your comments about the issue that we need to address the issue of transport, especially what is kind of interesting because from the military point of view, there is a lot of related issues that don't seem to be standing in the way of the United States government doing what it needs to be able to take care of the problem. Comments on the transport issue?

Dr. FERGUSON. So in France, they are transporting plutonium several hundred miles from the la Hague reprocessing facility in Normandy down to the Melox facility in the south of France. Now, they haven't had any security incidents that I am aware of and they have been doing this for many years. So, so far so good. But it only takes one incident. They are, you know, transporting several bombs' worth of plutonium in each shipment. So it is not that—the proliferation threat in countries like France, it is not that France would then use that commercial program to make its own nuclear weapons, it is that insiders might be able to sneak out some quantities of that material. As I point out in my testimony, only one-tenth of one percent of the material going through a bulk handling facility annually could be enough to make a nuclear bomb. Now, you pointed out the U.S. military. I used to be in the U.S. military, and I was in the U.S. nuclear Navy. We have a very good safety record, but we had a problem a couple of years ago in the U.S. Air Force. There was a bent spear incident in which some nuclear-armed cruise missiles were unaccounted for for 36 hours. Now, there wasn't an insider threat there, it was really just a bad mistake, accountability, but it does point out that even in organizations with high security standards, things can go missing. There is an opportunity for diversion.

Dr. PETERS. As you noted, it is not really a technical issue per se. The technologies exist. We do it safely and securely now domestically. It is all about public trust and confidence, and it is a social science issue if there is science in it and so it is about communication and people understanding the risks and whatnot at a level that they can understand and also talking to them very carefully about what the plans are and making it very transparent, and that is something that needs to be done. I mean, we have had success in the United States with shipments to the waste isolation pilot plant in New Mexico. I would say in general the transportation program there has been—has gone very well. So we have some experience domestically but it would be a long process of developing public trust and confidence.

Dr. HANSON. I would just like to echo what Mark Peters has just said. We have transported tens of thousands of casks of used fuel to our facilities in France without any incident. The containers which are used are, for all practical purposes, indestructible. There is a need to get public acceptance and that is a social science issue, not a technology issue. I think we have had a phobia in this regard for many, many years and we need to get over that phobia because we have to eventually move the material somewhere.

Mr. BILBRAY. Well, my time has expired but I just want to say I think that maybe I am suspicious of intention here but the phobia was almost promulgated by people based on the fact that they saw it as a way to destroy an energy source based on misperception and they use it as an excuse for an agenda that wasn't up front.

Thank you very much, Mr. Chairman, and again, thank you for holding this hearing. I hope to see us continue this. There may be one committee that wants to handle only the pieces of legislation that are marked H.R. that may not want to address the nuclear power issue but I am glad to see that we have been able to reserve this, mostly because they have been willing to avoid it, and I hope that you continue your leadership on the issue. Thank you.

Chairman GORDON. Thank you, Mr. Bilbray.

Dr. Hanson, if you want to confirm the indestructibility of those casks, I will loan you my daughter. That is the ultimate test.

Now, I would suggest that the Committee buckle their seatbelt and we recognize Ms. Woolsey for five minutes.

## SAFETY RISKS

Ms. WOOLSEY. Thank you very much. Mr. Chairman, I echo what Congressman Bilbray just said about you and how open you are and how good you are to all of us, even though I can't remember what Mr. Bilbray because it hurt my feelings so much, all those words about people like me that absolutely do not support nuclear energy, and it isn't because it is not a decent energy, it is because of human error and our lack of being able to handle waste and have a place for waste and transporting, and you know, it is a good energy until it isn't, and then look what we have got. We have another Hiroshima. I absolutely believe we should be using these same millions of dollars for other kinds of energy research until—I don't think it will ever be safe enough, and I just wanted to be up front with that, and I would—you know, there is solar, there is wind, there is waves, there is geothermal, there is all kinds of things we haven't even thought about because we are putting millions and millions of dollars into something that people really don't want to have in their neighborhood. So we have gone on and on about Yucca Mountain. Imagine, Dr. Hanson, if we tried to build a recycling plant in the United States of America to handle all of the nuclear waste worldwide. I can imagine trying to get through that argument in maybe 20, 30, 40, 50 years from now but I don't think that can happen now. Maybe some other country, maybe we could convince some poor country to take our waste and handle it, you know, on some island where we could just turn our backs on it, which I wouldn't support at all, but I am not—I mean, I know I am not going to convince you, you are not going to convince me. This is very good because I learned what all of you folks think is so important and why it is okay to invest in doing all of this when indeed we could have quite an accident here in the United States of America, and that is why we don't have new nuclear sites. How long has it been since we have had a new nuclear plant in the United States? Yes, Dr. Ferguson.

Dr. FERGUSON. In 1996, Watts Bar Unit 1 was the last plant to really come on operation.

Ms. WOOLSEY. And that is South Carolina?

Dr. FERGUSON. Tennessee, or TVA.

Ms. WOOLSEY. Oh, sorry.

Dr. FERGUSON. But that plant was ordered back in——

Chairman GORDON. Alabama, actually.

Dr. FERGUSON. I thought it was Tennessee, Tennessee Authority. But that was ordered back in 1970. So we haven't had a plant that has been ordered since about 1973 and gone completely to construction.

Ms. WOOLSEY. And what are the arguments against these plants that you are having to surmount?

Dr. FERGUSON. Well, I think it really boils down mostly to economics. I mean, there has been some public opposition, but if you look at the communities where nuclear power is being generated, they tend to be overwhelmingly supportive of nuclear power plants for jobs and the plants have become very safe compared to where we are with Three Mile Island. I grew up in Pennsylvania not too far from where the accident happened, so I remember what happened there 30 years ago, and I mentioned to Congressman Bilbray, I was in the U.S. nuclear Navy so I know what a safety program is like that meets high standards of excellence. What happened immediately after Three Mile Island was, the industry formed what is called INPO, the Institute for Nuclear Power Operations. It has been a self-policing organization that has been an industry watchdog. Now, it doesn't mean we don't need a Nuclear

Regulatory Commission, we do. We need a strong, independent regulator but INPO has served an important purpose in keeping the industry accountable, in a way kind of shaming them and doing peer reviews and making sure that they are living up to high standards, not that we haven't had problems. If you look at a plant in Ohio a few years ago at Davis-Besse, there was a potential accident in the making there.

Ms. WOOLSEY. So unless you want to——

Dr. PETERS. Well, I guess a little bit more. So the last one was brought on. Then there was another one brought online so we are currently operating 104 reactors, and the Nuclear Regulatory Commission has 17 combined construction/operating licenses that they are in the process of evaluating right now that could lead up to 26 new units. So right now what they are saying is, there could be new plants online by 2015, 2016. So they are moving forward. A lot of it is about the economics.

Ms. WOOLSEY. And for the same amount of investment, are there not safer ways to provide energy in the United States of America?

Dr. PETERS. In terms of cost per kilowatt-hour, it is competitive with coal.

Ms. WOOLSEY. How about risk?

Dr. PETERS. Well, they are all going to have their challenges. It is hard for me to put a price on risk, first of all, so I probably can't give you a clear answer to that. But what I will say right now is that we should be investing in all the things that you are talking about but those just aren't cost-competitive. More importantly, it is the reliability and the ability to produce a lot of electricity that you don't get from some things like solar and wind yet.

Dr. HANSON. If I may, I would like to correct one thing in your statement. There is no energy technology that is risk-free. That is certainly true, and nuclear has some unique hazards associated with it, but it has a very, very high safety record worldwide. There is no conceivable accident in the civilian nuclear power cycle that can get anywhere near the consequences of a Hiroshima. That is physically impossible. You mentioned who would want it. During the GNEP studies, 15 communities raised their hand and said we want to study putting a recycling facility in our community because of the economic benefits that would come with it. Finally, just to make the case for the fact that there is no such thing as a perfectly safe industry, the wind industry is—by the way, we make windmills too. But the wind industry is growing pretty fast in the U.K. and there is a very interesting company there that is making windmills and they are keeping track of the deaths caused by windmills, which at last count had reached 41 worldwide, and we haven't killed that many people with the nuclear industry in over 50 years of operation.

Chairman GORDON. Thank you, Dr. Hanson.

Ms. Woolsey, we need you to continue to ask the hard questions. Thanks for being here. Do you have a closing?

Ms. WOOLSEY. Well, my closing was my Chairman here from our subcommittee. What about Chernobyl?

Dr. HANSON. Chernobyl was a bad example with a bad reactor with no containment and poorly operated. The direct consequences in terms of death was exactly 31.

Chairman GORDON. Thank you, and Mr. Hall is recognized for five minutes.

Mr. HALL. Mr. Chairman, I want to yield maybe a minute of my time to Mr. Bilbray to expound a little further.

Mr. BILBRAY. Dr. Ferguson, you served in the United States Navy. What is the last reactor put online in this country?

Dr. FERGUSON. Well, in the U.S. Navy.

Mr. BILBRAY. Right.

Dr. FERGUSON. I don't know exactly what the reactor was.

Mr. BILBRAY. George Bush?

Dr. FERGUSON. Right.

Mr. BILBRAY. Ronald Reagan?

Dr. FERGUSON. Yes, sir.

Mr. BILBRAY. How many nuclear power units—who in the last 30 years have been the only purchasers of nuclear power in this country?

Dr. FERGUSON. Well that brings—well, the U.S. Navy, and it brings up a very important point about our workforce, and part of the work I am doing at the Council on Foreign Relations is analyzing the nuclear workforce and the shortages we have. If we really want to expand nuclear energy use, where are we going to get the skilled people to run these plants? We have been drawing them from the U.S. Navy but the Navy obviously needs these people as well. So our workforce is shrinking. The workforce is aging. They are nearing retirement age very rapidly.

Mr. BILBRAY. And the fact is, not only has the Federal Government continued to purchase and invest in nuclear power as its preferred source for large craft, but it also places it in the middle of high urban areas like San Diego Bay where you have multiple, multiple nuclear reactors right in the urban core, right?

Dr. FERGUSON. That is correct, and it also the submarine reactors are designed to go very deep. I can't tell you how deep, that is classified, but very deep and still operate very effectively.

Mr. BILBRAY. Mr. Chairman, thank you very much. I just wanted to point out how safe it was.

Mr. HALL. I will reclaim my time, and I would like to use my time to point out that this is the first difference I have ever had with Ms. Woolsey, I believe, is on nuclear energy.

Ms. WOOLSEY. Except you don't know how to pronounce my name yet.

Mr. HALL. I always call you Lynn. Okay. Let me use my time.

## MORE ON FAST REACTORS

Dr. Ferguson, a real quick answer from you on this if you would. You talked about fast reactors in your testimony, and I think you talked some more about them a little bit ago about reactors being able to breed new plutonium and how they were designed to do this. I think you covered that, but I didn't hear an answer as to why is France turning—why are they shutting down their fast reactor? I think it is Phoenix, isn't it, the prototype Phoenix?

Dr. FERGUSON. That is correct. They are shutting that down this year. They——

Mr. HALL. Why? Just give me a short answer to that.

Dr. FERGUSON. One very brief reason is, it is a political opposition to—their Super Phoenix was the big fast reactor. They shut that down in the mid-1990s, mainly for political reasons, but they were also having problems. I think one of the panelists mentioned or maybe one of the Congressmen mentioned about fast reactors. The history of fast reactors, we haven't really had a fast reactor ever operate even at 50 percent power capacity, so it is still an unproven technology. Phoenix, though, was designed to be a prototype, to be a test reactor, and it has served its purpose very well over a number of decades.

Mr. HALL. I thank you.

## SPECIFIC RESEARCH AND DEVELOPMENT NEEDS

Dr. Hanson, I didn't hear your testimony at the beginning. I was at another Committee meeting. But at end of your testimony, your written testimony, you talked about areas for research, development and demonstration and in particular you mentioned reducing the minimal gaseous and liquid discharges that might arise from the current processing technologies, electromagnetic separation and advanced instrumentation. Give us a little explanation of each of these, not that you can make me understand it but we would have it on the record.

Dr. HANSON. Thank you. I will try very briefly. When you shear and dissolve nuclear materials, you release some of the gases that are included in the fuel, and you can deal with it in a number of ways. One is by discharging them into the atmosphere as long as you stay within regulatory limits and the other thing that you can do is capture, package and dispose of them. We haven't done much research in that capture and control. Basically it is like carbon sequestration. We haven't done it because we haven't needed to do it. But if we are going to locate a recycling facility in the United States, I think we are going to have to meet some very strict limitations on the discharges and so we need research in that particular area. We have already talked about research on electro-metallurgical separations. That should continue in advance of the fast reactors. With regard to the safeguards, there is no doubt that you have to have safeguards and security associated with these types of facilities. In order to do that, you have to have very, very sophisticated instrumentation to measure the flows of material and to make sure that material is not surreptitiously removed from the facilities. There is a lot that can be done in this particular area and I think we can learn a lot from what the U.S. military has done and at the national labs in order to make the next-generation facility that is built even more proliferation resistant than the ones that are in existence today.

Mr. HALL. I thank you. I think my time is up. Thank you, Mr. Chairman.

Chairman GORDON. Thank you, Mr. Hall. We will have a test at the end of this hearing.

Dr. Baird is recognized for five minutes.

Mr. BAIRD. I thank the Chairman. I thank our witnesses, a fascinating topic. If I applaud you and praise you, Mr. Chairman, can I have an extra six minutes? It is a worthwhile hearing and we are grateful for your expertise.

## Economic Issues

I want to talk a little bit about the economics. You know, we do have a difficult choice before us. I happen to be absolutely convinced that the evidence is clear that the climate is changing, that the Earth is overheating and that the oceans are becoming acidified. So reducing $CO_2$ output makes a lot of sense. On the other hand, it is not just nukes or $CO_2$, there are a host of other technologies available. Talk to us a little bit about—I want to raise two quick issues. One, when people say carbon zero, there ain't no such thing. I mean, the net cost to extract uranium, transport the uranium, process uranium, build the concrete containment vessels, et cetera, there is a large carbon cost to that. So talk a little bit about that, but also talk to us a little bit about subsidies. When we talk about the relative economics of nukes versus alternatives, what kind of subsidies, government subsidies, go into the nuclear industry from front to back including insurance, including waste reprocessing, et cetera? And on the research side. Can you share that with us?

Dr. HANSON. If I may, I will try and address your first question and leave the second one to the panel. You are absolutely right. When you are trying to compare technologies, you need to look at life cycle carbon footprints and not just the emissions from the facility. The nuclear power plants basically are zero-emission plants. There is a carbon footprint associated with enrichment and building the plant and doing the mining. However, it is very small. If you look at the carbon footprint of the available technologies to produce electricity, what you will find is the lowest carbon footprint is nuclear and wind. They are almost identical. The carbon footprint of solar photovoltaics is very large, so much so that if you replace all the nuclear power plants with solar photovoltaics, you would increase carbon emissions by a factor of five. You need to look at these things. There are some very good studies that have been done in the U.K. and in the international community to make the comparison, and I would submit that nuclear energy is very, very carbon friendly.

Mr. BAIRD. Let us talk a little bit about subsidies then.

Dr. PETERS. So maybe I will speak to the R&D part perhaps is the place where I should start. So in the past there was significant investment in R&D in the old breeder reactor days back in the, you know, 1960s, 1970s, 1980s.

Mr. BAIRD. Let us include fusion in the——

Dr. PETERS. Right. So since the mid-1990s, then R&D went away for quite a while, and in the mid-1990s it started to ramp back up. So in a combination of the advanced fuel cycle initiative and Generation IV, you are looking at about $300 million a year going into R&D in nuclear energy.

Dr. FERGUSON. Two points I would like to make is that how many nuclear power plants do we need to build to really take a further bite out of climate change. If you look at a study from 2004, two Princeton researchers, Dr. Steven Pacala and Robert Socolow, they looked at the so-called wedge model and they break up the greenhouse gas emissions increases into seven equal wedges and asked, so if nuclear were going to fill one of those seven wedges, how many nuclear power plants would you need to have online by mid-century. You would need to have equivalent of about 1,000 1,000-megawatt electric power reactors on line by mid-century. Right now we have about the equivalent, just a little bit less than 400, the amount of plants online. That is an aging fleet. We are going to have to replace those reactors by mid-century so we are going to have to build that number of reactors, roughly 400, and build about another 600 in addition. Now, I know Areva is building the EPR, which is about a 1,600-megawatt electric plant. But the ballpark figure is that you have to build one new 1,000-megawatt electric plant, have it come on line every two weeks between now and mid-century to have a further significant reduction in greenhouse gases from nuclear power. It is a very—it is not impossible to do but it is very challenging. The last time we came close to that in the world was in the early 1980s when France and Japan were building nuclear reactors rapidly. So I just want to put that out there.

And in terms of subsidies, the question of, can we learn from other countries' experience? As I mentioned, I have been studying the French experience. Is the French model applicable to us? Well, they have very central government control. The French government owns Areva. They have a controlling stake in Areva. They own Electricité de France. We don't have that kind of situation in the United States. The French government was able to offer a loan structure to allow France to build now about 58 nuclear reactors that are now operating. We have 104 reactors operating, more than France, but in terms of proportional use, the French are ahead of us, about 80 percent to 20 percent. So the question is, does it make sense for us, what are the opportunity costs for us in giving the nuclear industry here in the United States, which is a relatively mature industry, billions of dollars, maybe even hundreds of billions of dollars, worth of loans to further stimulate nuclear power expansion.

Mr. BAIRD. And my main point would be that that cost needs to be factored into the per-kilowatt-hour, per-megawatt-hour cost, the subsidy, as we say. One technology superior to another on a cost perspective, there are a host of subsidies that ought to factor in that.

Dr. FERGUSON. You are right. We shouldn't be in the business of picking winners and losers. Two years ago I published a report that said that if you want to be supportive of nuclear power, you need to get the carbon pricing right, either through a carbon tax or cap and trade, set the right price. Nuclear would be on an equal playing field with coal and natural gas.

Ms. PRICE. If you take a look at the current price of commodities in the market today, what you would see is that nuclear with its subsidies and wind and solar with their subsidies, and even with natural gas in the $3 to $4 range where it has been in the $8 to $10 range, nuclear is straight up competitive with natural gas, and if you put a carbon tax on it, then it is more attractive and it is more attractive than wind and solar including the subsidies that they currently have today.

Mr. BAIRD. It is a grave shame that some of our colleagues are not here to have heard those prior statements. I thank the panelists.

Dr. HANSON. If I may, I would like to make one correction to what my friend Charles said. The nuclear industry, to my understanding, is not asking for billions of dollars of loans from the government, they are asking for loan guarantees for which they will pay, and so unless projects default, the net cash flow will be to the government and not from the government.

Mr. BAIRD. Coming from the state with WPPSS, I would be a little bit cautious about that last statement.

Dr. HANSON. Yes, no doubt.

Chairman GORDON. Thank you, Dr. Baird. As usual, very good and thoughtful line of questioning.

Mr. Inglis is recognized for five minutes.

Mr. INGLIS. Thank you, Mr. Chairman.

Dr. Ferguson, that was music to my ears, and I agree with Dr. Baird that I wish that a lot of our colleagues could have heard some of that last little bit. If you change the—if you internalize the externalities, negative externalities associated with some of these fuels that are the incumbent fuels, suddenly technology takes off and we start doing exciting things as clean nuclear power with no emissions and it is very, very exciting.

THE MOX PROCESS AND ON MORE FAST REACTORS

Dr. Hanson, I think I am right about this, I am not sure, so it is dangerous to ask a question if you don't know, but our former colleague from Ohio used to tell me all the time—Dave Hobson used to be critical of the MOX process, as I recall, and can you tell me what the—his objection, as I recall, was that what we are doing at Savannah River site, he says, he charges, it is old technology, we should be moving on to the new technology. I am wondering what your reaction to that is. Is he right? Is he wrong?

Dr. HANSON. It would be very dangerous of me to try and paraphrase Representative Hobson's position, but as I do understand it, he was supportive of the concept of recycling. He was not supportive of the MOX project in South Carolina for a number of reasons. In particular, he was very skeptical of the fact that the Russians would do their share which was to demilitarize at the same pace that we were doing it, and as the Russians slowed down, he became skeptical of the whole program. However, we have very important nonproliferation concerns and obligations under the NPT. We need to start destroying military plutonium, and that facility is going to do it. I never heard any criticism from him with regard to the technology. I did hear a lot of criticism of the Department of Energy and its seeming inability to control and bring projects to completion.

Mr. INGLIS. Ms. Price, is that your understanding what Dave Hobson's objection was, or do you remember?

Ms. PRICE. I am sorry. I don't know what his objections were.

Mr. INGLIS. What I heard him, Dr. Hanson, I think, is that he didn't like the technology. He thought that it was old. Is that—anybody want to comment about whether it is old or is in fact——

Dr. HANSON. It is not old, it is state-of-the-art and I never heard him make that comment.

Dr. PETERS. But I would say that, back to what the Russians are doing, so what the Russians have considered doing is actually taking care of the plutonium in a fast reactor as opposed to going to MOX and thermal recycle. And this gives me an opportunity. The fast reactor discussion by the panel, I encourage the Committee to look more deeply into fast reactor experience because there is—it is extensive experience in the United States and worldwide and there is currently demonstration fast reactors being constructed in other countries. So I wouldn't want to say that—it is not an unproven technology. So I think it would behoove us to look at that much more carefully before we just dismiss it as an unproven technology. I think it needs to be developed further.

Mr. INGLIS. A quick explanation of that technology. How does that work?

Dr. PETERS. Well, there are different ways of cooling it. As opposing to being moderated by water, it is moderated by perhaps liquid metal like liquid lead or liquid sodium, and the difference is how fast the neutrons travel inside the core. So instead of building up a lot of isotopes higher than uranium, you can actually configure the core such that you can burn it down. So it is slow neutrons versus fast neutrons. So in the case of a fast reactor, you can use it to actually burn down material and also perhaps breed material.

Mr. INGLIS. Got you.

Ms. PRICE. One point I would like to add to that in the context of whether there is better technology than MOX for addressing plutonium, if you do bring the plutonium and if you do use the plutonium in a MOX context, you still end up with spent nuclear fuel on the back end that you actually have to then turn around and handle. If you burn it in a fast reactor, you are actually consuming the plutonium and so that is the basis. I would assume that he would say look, there are technologies that can more completely consume it and reduce the waste that you have to deal with on the back end.

Mr. INGLIS. Dr. Ferguson.

Dr. FERGUSON. I have been to Japan. I was there a couple of years ago, visited Monju, their fast reactor site. They had an accident on the secondary, sort of the non-nuclear side of their fast reactor. They used liquid sodium for the coolant, and the property of sodium—remember your high school chemistry class where you take some sodium and you strip it and you put it in some water and what happens? It goes like crazy. It catches on fire. So they had a sodium fire at that facility and the Japanese are being very cautious in bringing that facility back up again. They have had some public opposition about that fast reactor. They are trying to educate the public about trying to re-operate that reactor, so that is Japan's experience. I mentioned France's experience earlier to Mr. Hall. But it is a mixed record. I think, you know, Dr. Peters is making a good point here. We need to take a fresh look at fast reactor technology, and Ms. Price also makes a good point. It can offer some significant benefits if it is economically effective, if we can handle some of the safety problems we have had in the past with some of these reactors.

Mr. INGLIS. Thank you, Mr. Chairman.

CLOSING

Chairman GORDON. Thank you, Mr. Inglis. And once again, let me thank the panel for a very thought-provoking discussion and helping to raise our understanding of these issues. We want to continue this dialogue. We thank you for that. The record will remain open for two weeks for additional statements from Members and for answers to any follow-up questions the Committee may ask of the witnesses.

The witnesses are excused.

[Whereupon, at 11:58 a.m., the Committee was adjourned.]

# Appendix:

## Additional Material for the Record

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**Honorable Dana Rohrabacher**
**U.S. House of Representatives**
**Washington, DC**

**June 16, 2009**

**Subject: Joint US-Russian Development of the Advanced Gas Reactor**

**Dear Congressman Rohrabacher,**

**A we talked earlier today, it is time to upgrade the relations between the U.S. and Russia, particularly in the area of nuclear power: it is time to move from a relationship where the U.S. provides technical assistance to Russia to a real partnership for improving global energy and economy, environment and non-proliferation. I believe that the best developed and most fruitful area where the U.S. and Russia can perform nuclear cooperation is in the joint development of the High Temperature Gas Reactor.**

**There are many reasons why this makes sense:**

> **First, its high operating temperatures allow for very efficient electric power generation and for its use as a greenhouse gas free means of providing process heat for the production of hydrogen, the extraction and refining of tar sands, the manufacturing of chemicals and fertilizer, and many other industrial uses that are now solely dependent on fossil fuel. In the near term, no other reactor can make such a claim and have such a profound impact for our environment and energy security.**
>
> **Second, it can be easily configured to burn plutonium and the most long-lived and toxic components of spent nuclear fuel and therefore can help improve the nuclear fuel cycle;**
>
> **Third, the HTGR is highly proliferation resistant;**

**I want to emphasize here the security and non-proliferation benefits of this reactor by reminding you that the basis of the HTGR is fuel that has impenetrable ceramic coatings that not only retain the products of nuclear fission well, but they are much more difficult to reprocess than conventional light water reactor fuel. In addition, this same fuel cladding makes it possible to achieve a more complete burning of uranium fuel, but also the ability to deeply burn spent nuclear fuel.**

**The U.S. and Russia must work together to not only bring the benefits of this reactor to both of our countries, but to provide this same proliferation resistant and secure type of**

**reactor to other less developed countries who are moving quickly to harness the benefits of nuclear energy. In this way, we can make great progress in non-proliferation and economic development without harming our environment.**

**Sincerely Yours**

16.06.2009

**N. Ponomarev-Stepnoy**

AREVA

June 17, 2009

Congressman Bart Gordon
Chairman of the House Committee on Science & Technology
2306 Rayburn HOB
Washington, DC 20515

Dear Chairman Gordon:

At today's hearing on "Advancing Technology for Nuclear Fuel Recycling," you asked an important question which I will paraphrase: "Do we move forward on recycling using existing technologies or do we leapfrog directly to future technologies?" You may recall that I was skeptical of our ability to successfully leapfrog to a future technology and instead recommended we proceed as a nation to move expeditiously to recycling using current, cutting-edge technology.

Upon reflection I recalled an example where the U.S. tried unsuccessfully to leapfrog with nuclear technology. The example I am referring to is uranium enrichment. In the recent past uranium enrichment was provided commercially primarily by the U.S., France, and the U.K. using the gaseous diffusion plants originally constructed for the purpose of making weapons materials. These plants were quite inefficient and very energy intensive. Therefore, each nation sought to use a new technology with much lower energy consumption requirements. The next-generation technology turned out to be gas ultra-centrifugation—it was the evolutionary technology of choice.

In the U.S., development of gas centrifuge technology was pioneered at the Oak Ridge National Laboratory where good progress was being made. However, within the DOE laboratory complex a competing, revolutionary technology was being researched based on using lasers for enrichment. The concept was called AVLIS and was centered at Lawrence Livermore National Laboratory. As scientists in the U.S. watched the Europeans and the Russians make rapid progress on their centrifuge programs, it was decided to "leapfrog" centrifuge enrichment and proceed directly to laser enrichment. Scientists at LLNL assured the DOE that AVLIS technology was just around the corner and that we should not waste our time with centrifuge enrichment which would become yesterday's technology.

I do not need to remind you of what a disastrous decision this was both for the nation and for USEC which continued with the AVLIS program after its creation as a private entity. AVLIS did not work as expected, was not scalable, and was eventually abandoned after more than a decade was lost trying to make it work along with an expenditure of more than $2 billion. USEC was forced to return to "yesterday's" technology—centrifuges. But at this point the U.S. and USEC were more than a decade behind the Europeans and Russians in technology development. The result was a great loss of market share and the prospect today that USEC may not be able to catch up either technologically or commercially.

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The situation we face today with recycling is virtually identical to the case of enrichment just cited; even some of the players are the same. A number of national laboratories are advocating that the U.S. leapfrog over existing successful aqueous processing technology and go directly to "advanced" aqueous processing or to pyroprocessing, neither one of which has been demonstrated to be scalable or commercially viable. I fear that if the U.S. makes such a decision the result will be the same as with AVLIS and instead of leap-frogging out in front, the U.S. will find itself even further behind the rest of the world.

I can also cite another failed leap. In the 1970's General Electric (GE) decided to get into the business of reprocessing. Instead of using the PUREX process which was already well established and in use in the U.S., they built a plant in Morris, Illinois based on their new laboratory-scale process called Aquafluor. While testing the plant with uranium, GE discovered that the $64 million plant they built could not possibly work as predicted. They abandoned reprocessing. Today that plant still exists in Illinois contaminated with yellow uranium dust and storing spent fuel awaiting plant operation that will never come.

The lessons could not be clearer—a leap in the nuclear area is a very risky undertaking that rarely, if ever, is successful. Please do not misunderstand; AREVA is very supportive of R & D on advanced recycling technologies. However, if we as a nation wish to be successful in mounting a recycling program, we should do this in a careful, deliberate manner first using best-available current technology. This will provide useful experience for a new cadre of nuclear professionals and help to rebuild a supply chain which has been allowed to wither in this country. There will be plenty of time to transition to advanced processing technologies when they have been developed to the stage where they are proven and commercially viable.

Again, I want to thank you for the invitation to testify. Your Committee members asked interesting and pointed questions. I hope that the responses from the witnesses met your expectations. As always, I would be pleased to answer any other questions you or your committee would have.

Sincerely,

Alan S. Hanson

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