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

Prepared Testimony

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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. re-fissioning 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 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% 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 electrometallurgical 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 20-22, 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 3 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 3Rs. Two questions must be answered for a full understanding of the 3 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 5 percent down to less than 1 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 4 percent), and new transuranics (about 1 percent). This 1 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 3 Rs. Figure 1 shows the reduction in heat over time for each of the 3Rs:

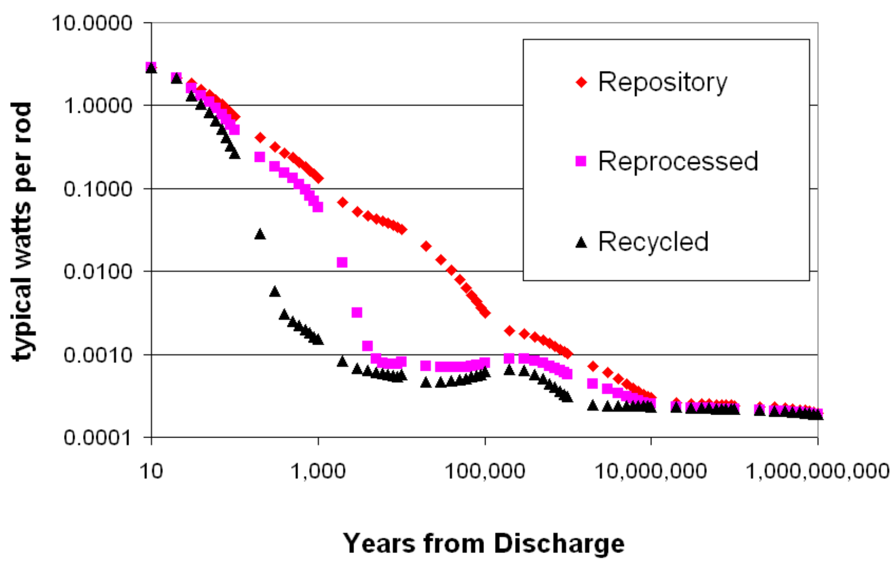

Figure 1: Long-Term Heat Generation Consequences—Repository, Reprocess, Recycle

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 3Rs 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 electrometallurgy); 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.

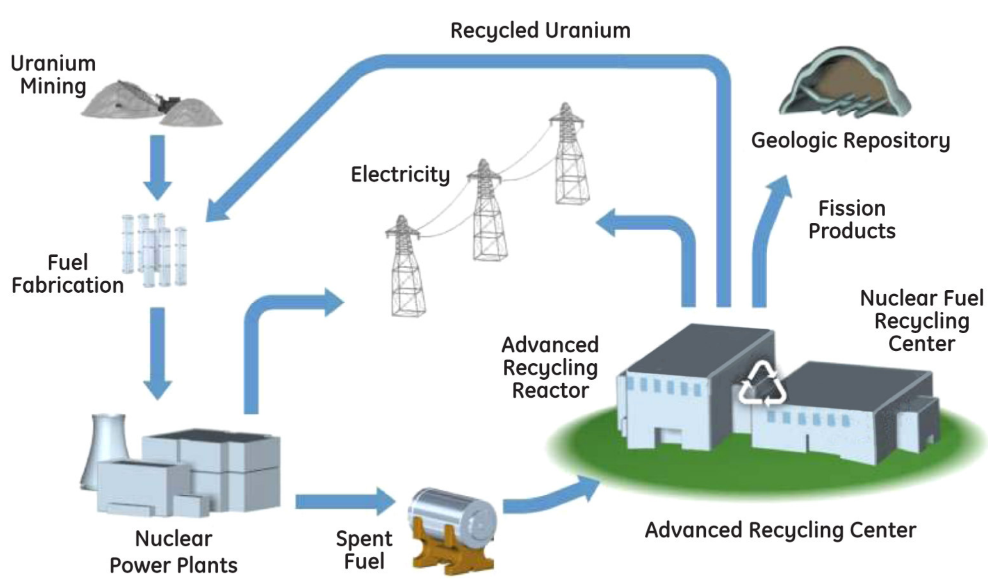

Figure 2: GEH Advanced Recycling Center to close the fuel cycle in the future.

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 5 metric tons of plutonium (melting classified shapes with the correct amount of uranium and zirconium, producing the metallic alloy U-Pu-Zr) 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 reestablishment 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, electrometallurgical, 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 electrometallurgical 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 electrometallurgical 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 electrometallurgical 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.