Meeting the Challenge of Used Nuclear Fuel Management: Developing New Sustainable Technologies to Enable America's Nuclear Future

Testimony to U.S. House of Representatives Committee on Science, Space, and Technology

Mark T. Peters, Argonne National Laboratory

October 27, 2011

Summary

The Blue Ribbon Commission's (BRC) draft recommendation to move forward expeditiously with siting, licensing, and operating a storage and disposal system to manage legacy and future used nuclear fuel is an important and necessary step to enabling a sustainable nuclear energy future. A storage and disposal system is required in any nuclear fuel cycle. The BRC recommendation to conduct a robust advanced fuel cycle R&D program to inform future domestic fuel cycle options and maintain United States leadership in the global nuclear energy and fuel cycle enterprise is also important. Given the necessary linkages between fuel cycle technologies and ultimate disposition of nuclear waste, it seems most rational and efficient to address the challenges of advanced fuel cycle technologies concurrently with the broader policy questions of America's nuclear waste management program. Real progress in addressing these challenges is possible only within the context of a thoughtful, consistent policy for nuclear waste management, one that acknowledges the reality that a once-through fuel cycle will not be sustainable if global nuclear energy generation increases substantially.

Our national policy must include substantial support for a robust advanced fuel cycle research and development program that is focused on outcomes, that is closely integrated with storage and disposal efforts, and that ultimately leads to down-selection, demonstration, and deployment of effective advanced fuel cycle technologies. To that end, the United States should conduct a science-based, advanced nuclear fuel cycle research, development, and demonstration program to evaluate recycling and transmutation technologies that minimize proliferation risks and environmental, public health, and safety impacts. This program should be carried out through robust public-private partnerships involving the Department of Energy (DOE), its national laboratories, universities, and industry, and it should be conducted with a sense of urgency and purpose.

Introduction

For decades, the United States has grappled with the multiple challenges of crafting a long-term solution for the management of legacy and future used nuclear fuel. Over this past year, these persistent challenges have taken on new urgency as the accident at Japan's Fukushima Daiichi nuclear power plant has focused international attention on the safety and security of used nuclear fuel storage. Today, as we consider the BRC draft recommendations on America's nuclear energy future, it is critically important for us to take a close look at the scientific and technological challenges that must be addressed if we are to succeed in managing our used nuclear fuel.

We must keep in mind, however, that real technical progress is possible only within the context of a thoughtful, consistent policy for nuclear waste management. Our national policy must include substantial support for a robust advanced fuel cycle research and development program that is focused on outcomes, that is closely integrated with storage and disposal efforts, and that ultimately leads to down-selection, demonstration, and deployment of effective advanced fuel cycle technologies. Only a reasoned plan for research, development, and deployment can lead to a decision on a preferred fuel cycle technology that will enable safe, sustainable expansion of the U.S. nuclear fleet.

I concur with the BRC recommendation for prompt action regarding siting, licensing, and operation of storage and disposal systems to manage used nuclear fuel. Yet while I understand the Commission's conclusion that it is premature to seek consensus on the policy question of whether the United States should commit to closing the fuel cycle, I believe the BRC draft report's omission of this issue will result in a missed opportunity to inform U.S. nuclear waste policy going forward. As the draft report notes: "Future evaluations of potential alternative fuel cycles must account for linkages among all elements of the fuel cycle, (including waste transportation, interim storage and disposal)". Given those necessary linkages between fuel cycle technologies and ultimate disposition of nuclear waste, it seems most rational and efficient to address the challenges of advanced fuel cycle technologies concurrently with the broader policy questions of America's nuclear waste management program.

To that end, as I have testified previously to the House of Representatives, I believe that the United States should conduct a science-based, advanced nuclear fuel cycle research, development, and demonstration program to evaluate recycling and transmutation technologies that minimize proliferation risks and environmental, public health, and safety impacts. This program should be carried out through robust public-private partnerships involving the Department of Energy (DOE), its national laboratories, universities, and industry, and it should be conducted with a sense of urgency and purpose. To be most effective, this program must support evaluation of alternative national strategies for commercial used nuclear fuel disposition in close conjunction with ongoing efforts to site and develop a permanent geologic repository(s).

Sustainable Nuclear Energy

The ongoing challenge of America's nuclear waste management program must not be considered in a vacuum. World energy demand is increasing at a rapid and largely unsustainable pace; each year, humans consume an average of 15 trillion watts of electricity and release over 30 gigatons of carbon into the atmosphere, and worldwide energy use is expected to soar over the coming decades. To satisfy national and worldwide energy demand, reduce greenhouse gas emissions, and protect the environment, energy production must evolve from current reliance on fossil fuels to a more balanced, sustainable approach based on abundant, clean, and economical energy sources. At present, nuclear energy is the sole proven, reliable, abundant, affordable, and "carbon-free" source of electricity generation for the United States and the world. However, our current capacity for nuclear generation is not sufficient to support the goals of reliable, carbon-free, and affordable energy. Additionally, most existing nuclear power plants in the United States will reach the end of their operating licenses in the next few decades. At present, it is extremely unlikely that renewable energy sources, such as solar, wind, hydro, and geothermal energy, will be sufficient to replace that reliable, base-load capacity when those nuclear power plant licenses expire. So we must work swiftly and urgently to devise economically viable, environmentally responsible means to extend, replace, and add to the generating capacity of America's 104 existing nuclear power plants, which now produce nearly 20% of our electricity.

As we seek to expand our portfolio of sustainable energy sources, we must take into account the national and international response to the accident at the Fukushima Daiichi nuclear power plant, which occurred in the aftermath of the devastating earthquake and tsunami that struck northeastern Japan on March 11, 2011. The Fukushima accident has led to worldwide uncertainty about the future of nuclear power; in response, Germany, Switzerland, and Italy have announced plans to phase out or cancel all existing and future reactors. To a great extent, our future capacity for nuclear energy generation will depend on our ability both to safely dispose of nuclear waste and – perhaps even more importantly – to assure the public of the safety and security of our used nuclear fuel. Failure to find new, workable solutions to the continuing problem of nuclear waste management will have serious long-term ramifications for our national economy and future global competitiveness.

In considering the draft recommendations of the Blue Ribbon Commission, I believe it is vital to make advanced nuclear fuel cycle research a critical component of our long-term strategy for nuclear waste management, and that our national strategy must simultaneously address issues of economics, uranium resource utilization, nuclear waste minimization, and a strengthened nonproliferation regime. All of these issues will require both systems analysis and substantial, consistent investments in research and development, demonstration, and test and evaluation, with those efforts directed toward the ultimate goal of a closed fuel cycle for waste and resource management.

Used Nuclear Fuel Management

It is the composition of used nuclear fuel that make its ultimate disposal challenging. Fresh nuclear fuel is composed of uranium dioxide (about 96% Uranium-238, and 4% Uranium-235). During irradiation, most of the Uranium-235 is fissioned, and a small fraction of the Uranium-238 is transmuted into heavier elements known as transuranics. The used nuclear fuel contains about 93% uranium (mostly Uranium-238), about 1% plutonium, less than 1% minor actinides (neptunium, americium, and curium), and about 5% fission products. Uranium, if separated from the other elements, is relatively benign, and could be disposed of as low-level waste or stored for later re-use. However, some of the other byproducts raise significant concerns:

- The fissile isotopes of plutonium, americium, and neptunium are potentially usable in weapons and therefore raise proliferation concerns. However, used nuclear fuel remains intensely radioactive for more than 100 years. Without the availability of remote handling facilities, these isotopes cannot be readily separated, essentially protecting them from diversion.
- Three isotopes, which are linked through a decay process (Plutonium-241, Americium-241, and Neptunium-237), are the major contributors to long-term radiotoxicity (100,000 to 1 million years). Hence, they are potential significant dose contributors in a repository, and also major contributors to the long-term heat generation that is a key design limit to the amount of waste that can be placed in a given repository space.
- Certain fission products (notably cesium and strontium) are major contributors to any storage or repository’s short-term heat load, but their effects can be mitigated through engineering controls.
- Other fission products, such as Technetium-99 and Iodine-129, also contribute to long- term potential dose in a repository.

The time scales required to mitigate these concerns are daunting: several of the isotopes of concern will not decay to safe levels for hundreds of thousands of years. Thus, the solutions to long-term disposal of used nuclear fuel are limited to three options (not necessarily mutually exclusive): the location of a geologic environment that will remain stable for that period; the identification of waste forms that can contain these isotopes for that period; or the destruction of these isotopes. These three options underlie the major fuel cycle strategies that are currently being developed and deployed in the United States and abroad.

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 envisioned by the United States, involves treating used nuclear fuel as waste, with ultimate disposition of the material in a geologic repository (see Figure 1).

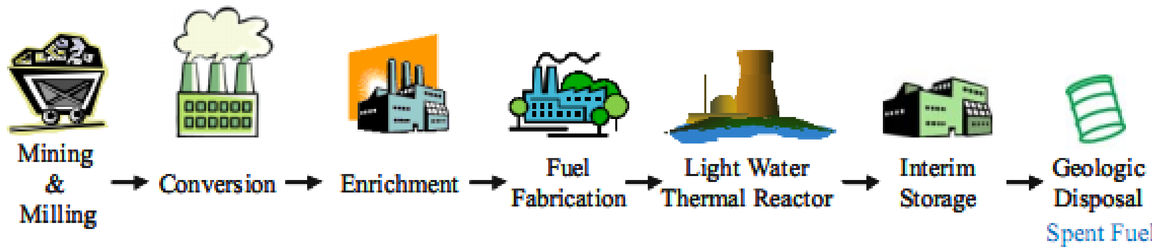

Figure 1. Open (or once-through) nuclear fuel cycle

In contrast, a closed (or recycle) fuel cycle, as currently planned by other countries (e.g., France, Russia, and Japan), treats used nuclear fuel as a resource, separating and recycling actinides in reactors and using geologic disposal for remaining wastes (see Figure 2).

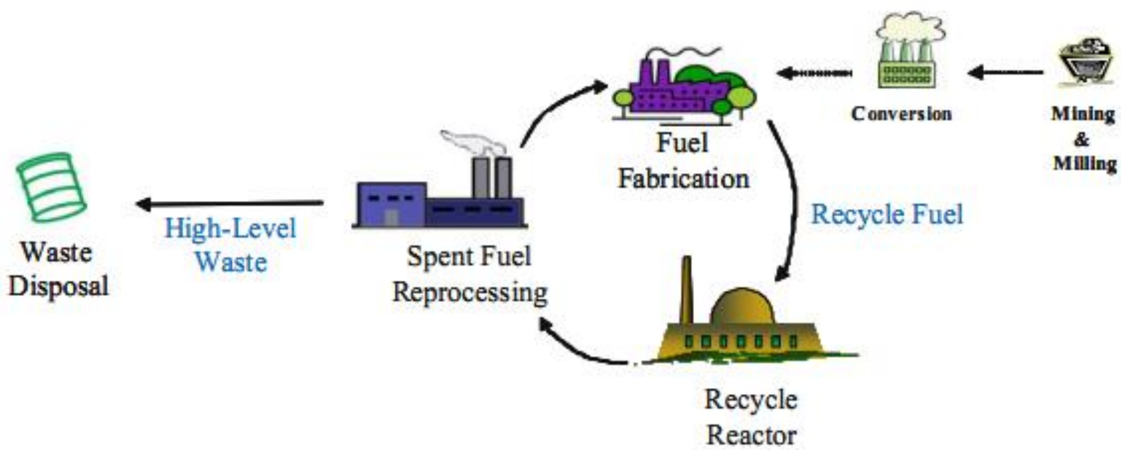

Figure 2. Closed nuclear fuel cycle (or reprocessing/recycling)

The open nuclear fuel cycle relies on disposition of used nuclear fuel in a geologic repository that must contain the constituents of that fuel for hundreds of thousands of years. Several countries have programs to develop these repositories. This approach is considered safe, provided suitable repository locations and space can be found. As noted in the BRC draft report, the challenges of long-term geologic disposal of used nuclear fuel are well recognized and are related to the uncertainty about both the long-term behavior of used nuclear fuel and the geologic media in which it is placed.

For the closed nuclear fuel cycle, limited recycle options are commercially available in France, Japan, and the United Kingdom. These nations currently use the Plutonium and Uranium Recovery by Extraction (PUREX) process, which separates uranium and plutonium and directs the remaining transuranics to vitrified waste, along with all the fission products. In this process, uranium is stored for eventual reuse and plutonium is used to fabricate mixed-oxide fuel that can be used in conventional reactors. Used mixed-oxide fuel currently is not reprocessed, though the feasibility of mixed-oxide fuel reprocessing has been demonstrated. It is typically stored for eventual disposal in a geologic repository. Although a reactor partially loaded with mixed-oxide fuel can destroy as much plutonium as it creates, this approach results in increased production of americium, a key contributor to the heat generation in a repository.

This limited recycle approach has two significant advantages:

- It can help manage the accumulation of plutonium.
- It can significantly reduce the volume of used nuclear fuel and high-level waste destined for geologic disposal. For example, the French experience indicates that this limited recycling can achieve volume reductions by a factor of 5 to 10.

However, there are several disadvantages to the PUREX process:

- It imposes a small economic penalty by increasing the net cost of electricity a few percent.
- The separation of pure plutonium in the PUREX process is considered by some to be a proliferation risk.
- This process does not significantly improve the use of the repository space (the improvement is around 10%, as compared to many factors of 10 for closed fuel cycles).
- This process does not significantly improve the use of natural uranium (the improvement is around 15%, as compared to several factors of 10 for closed fuel cycles).

Full recycle approaches are currently being researched in France, Japan, China, Russia, South Korea, India, and the United States. These typically comprise three successive steps: an advanced separations technology that mitigates the perceived disadvantages of PUREX, partial recycle in conventional reactors, and closure of the fuel cycle in fast reactors. Note: the middle step can be eliminated and still attain the waste management benefits; inclusion of the middle step is a fuel cycle system-level consideration.

The first step, using advanced separations technologies, allows for the separations and subsequent management of high-purity product streams. These streams are:

- Uranium, which can be stored for future use or disposed of as low-level waste.
- A mixture of plutonium and neptunium, which is intended for partial recycle in

conventional reactors, followed by recycle in fast reactors.

- Separated fission products intended for short-term storage, possibly for transmutation, and for long-term disposal in specialized waste forms.
- The minor actinides (americium and curium) for transmutation in fast reactors.

The advanced separations approach has several advantages:

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

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

The third step, closure of the fuel cycle using fast reactors to transmute the fuel constituents into much less hazardous elements, and advanced reprocessing technologies to recycle the fast reactor fuel, constitutes the ultimate step in realizing sustainable nuclear energy. This process will effectively destroy the transuranic elements, resulting in waste forms that contain only a very small fraction of the transuranics (less than 1%) and all fission products. These technologies are now being developed in the U.S. at Argonne National Laboratory and Idaho National Laboratory, with parallel development internationally (e.g., Japan, France, and Russia).

Several disadvantages have been noted for a closed fuel cycle, including:

- Increased cost. (Note that, in practice, closed fuel cycle processes actually would have limited economic impact; the increase in the cost of electricity would be less than 10%.).

- Expected increased generation of low-level waste, although this increase might be addressed successfully through improved technologies.
- Management of potentially weapons-usable materials may be viewed as a proliferation risk.

These disadvantages can be addressed through a robust research, development, and demonstration program focused on advanced reactors and recycling options. In the end, the full recycle approach has significant benefits:

- It can more effectively utilize repository space.
- It can effectively increase the use of natural uranium.
- It eliminates the uncontrolled buildup of isotopes that are a proliferation risk.
- An advanced reactor and associated processing plant can be deployed in small co-located facilities that minimize the risk of material diversion during transportation.
- A fast reactor does not require the use of very pure, weapons-usable materials, thus decreasing proliferation risk.
- Finally, full recycle can usher the way towards full sustainability to prepare for a future time when uranium supplies may become increasingly difficult to obtain.

In summary, the overarching challenge associated with the choice of any fuel cycle option is used nuclear fuel management. While geologic repositories will be needed for any type of nuclear fuel cycle, a closed fuel cycle would result in very different use of a repository. For reprocessing to be beneficial (as opposed to counterproductive), it must be followed by recycling, transmutation, and destruction of the long-lived radiotoxic constituents (i.e., plutonium, neptunium, americium). Reprocessing (with PUREX) followed by thermal-recycling (mixed-oxide [MOX] fuel in light water reactors [LWRs]) is well established, but is only a partial solution. It is not at all clear that the United States should embark on this path, especially since we have not made a large investment in a PUREX/MOX infrastructure. (N.B. The U.S. is proceeding with a plan to reduce excess-weapons plutonium inventory using MOX in LWRs.) In contrast, advancement of fast reactor technology for transuranic 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. These differences illustrate the importance of integrating advanced fuel cycle technology research and development into any national plan to address nuclear waste management.

As we approach this subject, we also must remember that, while there is no urgent need to deploy recycling today, a once-through fuel cycle will not be sustainable if global nuclear energy generation increases substantially. To maximize the benefits of nuclear energy in an expanding nuclear energy future, it will be necessary to close the fuel cycle.

Detailed Discussion

Argonne National Laboratory

Located 25 miles southwest of Chicago, Argonne National Laboratory is a direct descendant of the University of Chicago's Metallurgical Laboratory, where Enrico Fermi and his colleagues created the world's first controlled nuclear chain reaction. Appropriately, Argonne's first mission 64 years ago was to develop nuclear reactors for peaceful purposes. Managed by the UChicago Argonne, LLC for the U.S. Department of Energy, Argonne has grown into a multidisciplinary laboratory with a unique mix of world-class scientists and engineers and leading-edge user facilities, working to create new technologies that address the most important scientific and societal needs of our nation.

Argonne's experience over many years of research and development in the advancement of nuclear energy positions it as a leader in the development of future generation reactors and fuel cycle technologies. A primary goal of Argonne's nuclear energy research program is to advance the sustainable use of nuclear energy through research and development of technologies that enable waste minimization, enhanced resource utilization, competitive economics, and increased assurance of reliability, safety, and security. Expertise in reactor physics, nuclear and chemical engineering, computational science and engineering, and fuel cycle analysis is applied in the assessment and conceptual development of advanced nuclear energy systems that meet these important goals.

In collaboration with other DOE laboratories and universities, Argonne is advancing a science- and simulation-based approach for optimizing the design of advanced nuclear energy systems and assuring their safety and security. This approach seeks increased understanding of physical phenomena governing system behavior and incorporates this understanding in improved models for predicting system performance in operating and off-normal situations. Once validated, these models allow the simulation and optimization of system design and operation, to enhance safety assurance and cost competitiveness with alternative energy supply options. They also promise to accelerate the demonstration of commercially attractive systems in partnership with industry.

Primarily, the DOE's Office of Nuclear Energy (DOE-NE), through its Fuel Cycle Research and Development program, supports Argonne's waste management and reprocessing research and development activities. The objective of Argonne's research in this area is to develop and evaluate separations and treatment processes for used nuclear fuel that will enable the transition from the current open fuel cycle practiced in the U.S. to a sustainable, environmentally acceptable, and economic closed fuel cycle.

Our research focuses on the science and technology of chemical separations for the treatment of used fuel from both commercial and advanced nuclear reactors, used fuel characterization techniques, and waste form engineering and qualification. Ongoing projects related to reprocessing and waste management include:

- Using advanced modeling and simulation coupled with experiments to optimize the design and operation of separations equipment.
- Exploring an innovative one-step extraction process for americium and curium, radionuclides that are major contributors to nuclear waste toxicity, to reduce the cost of used-fuel treatment.
- Further developing pyrochemical processes for used fuel treatment. These processes enable the use of compact equipment and facilities, treatment of used fuel shortly after discharge from a reactor, and reduction of secondary waste generation.
- Developing highly durable and leach-resistant waste forms of metal, glass, and ceramic composition for safe, long-term disposal.

In addition, Argonne's nuclear science and engineering expertise utilizes theory, experiment, and modeling and simulation in the assessment and conceptual development of innovative, advanced reactors operating with a variety of coolants, fuel types, and fuel cycle schemes. Argonne also leads U.S. development of innovative technologies that promise to reduce the cost of fast-neutron reactors and increase their reliability. These technologies include high-performance fuels and materials; compact, low-cost components for the heat transport systems; advanced power conversion and refueling systems; and improved capabilities for in-service inspection and repair.

Argonne's research into the behavior of irradiated fuels and materials supports the U.S. Nuclear Regulatory Commission (NRC) in the regulation of industry initiatives to extend the operational lifetime and optimize the operation of existing and evolutionary nuclear reactors. Leading-edge systems analysis and modeling capabilities are used to assess the relative merits of different advanced nuclear energy systems and fuel cycles for various domestic and global scenarios of energy demand and supply consistent with environmental constraints and sustainability considerations. Argonne also has expertise in the components of nuclear technology that are critical for national security and nonproliferation, including the conversion of research reactors to low-enrichment fuels, technology export control, risk and vulnerability assessments, and national-security information systems.

Current Nuclear Waste Reprocessing Technologies

PUREX

As discussed above, current commercial used nuclear fuel reprocessing technologies are based on the PUREX process, a solvent extraction process that separates uranium and plutonium and directs the remaining minor actinides (neptunium, americium, and curium) along with all of the fission products to vitrified waste. The PUREX process has over 50 years of operational experience. For example, the La Hague reprocessing facility in France treats used fuel from domestic and foreign power reactors. The plutonium recovered is recycled as a mixed-oxide fuel to generate additional electricity. This technology is also used for commercial applications in the United Kingdom and Japan.

There are a number of drawbacks to the PUREX system. PUREX does not recover the minor actinides (neptunium, americium, curium, and heavier actinide elements), which compose a significant fraction of the long-term radiotoxicity of used fuel. Advanced reactors can transmute and consume minor actinides if they are separated from other fission product elements, but incorporation of minor actinide separations into existing PUREX facilities adds complexity and is outside commercial operating experience. Moreover, existing international facilities do not capture fission gases and tritium; these are discharged to the environment within regulatory limits. Although plutonium is recycled as mixed oxide fuel, this practice actually increases the net discharge of minor actinides. Finally, the production of pure plutonium through PUREX raises concerns about materials security and proliferation of nuclear weapons-usable materials.

PYROPROCESSING
Pyroprocessing is currently being used at the Idaho National Laboratory to treat and stabilize used fuel from the decommissioned EBR-II reactor. The key separation step, electrorefining, recovers uranium (the bulk of the used fuel) in a single compact process operation. Ceramic and metallic waste forms, for active metal and noble metal fission products respectively, are being produced and have been qualified for disposal in a geologic repository. However, the demonstration equipment used for this treatment campaign has limited scalability. Argonne has developed conceptual designs of scalable, high-throughput equipment as well as an integrated facility, but to date only a prototype advanced scalable electrorefiner has been fabricated and successfully tested.

Advanced Reprocessing Technologies

Research on advanced reprocessing technologies focuses on processes that meet U.S. non-proliferation objectives and enable the economic recycling of long-lived actinides in used fuel, while reducing the amount and radiotoxicity of high-level wastes that must be disposed. Main areas of research include:

- Aqueous-based Process Design - Current studies target the simplification of aqueous processes that can recover the long-lived actinides as a group in one or two steps.
- Pyrochemical-based Process Design - Present work is focused on development of scalable, high-throughput equipment and refining our understanding of the fundamental electrochemical process. We are targeting greater control of the composition of the recovered uranium/transuranic alloy, which will facilitate safeguards consistent with U.S.

non-proliferation goals.

- Off-gas Treatment – Environmental regulations limiting the release of gaseous fission products require the development of materials that will efficiently capture and retain volatile fission products. Because these volatile fission products are generally difficult to retain, development of novel materials with strong affinities for specific fission products is essential.
- Product/Waste Fabrication – This development effort includes concentrating the product streams and recovery/recycle of process fluids, solidification of products for both waste form and fuel fabrication/recycle. The products must meet stringent requirements as nuclear fuel feedstocks or must be suitable for waste form fabrication.
- Process Monitoring and Control - Advanced computational techniques are being developed to assess and reduce uncertainties in processing operations within a plant. Such uncertainties in design, in processing, and in measurements significantly increase costs through increased needs for large design margins, material control and accounting, and product rework.
- Sampling Technologies - The tracking of materials is critical to the safeguarding and operational control of recycle processes. Improving the accuracy of real-time measurements is a major goal for material accountancy and control. Reducing the turnaround time for analysis by applying state-of-the-art sampling and analytical techniques will enable "on-line" material accountancy in real time. Advanced spectroscopic techniques are under study to reduce gaps in our ability to identify key species at key locations within a plant.

Impact on Future Nuclear Waste Management Policy

The BRC draft report details possible solutions for the ultimate disposal of used nuclear fuel in the United States. To be most effective, these efforts should proceed in parallel with advances in used fuel processing and recycling, to ensure development of a fully integrated policy for nuclear waste management in the United States – one that is consistent with our energy security, nonproliferation, and environmental protection goals.

As previously noted, high-level waste disposal facilities are required for all fuel cycles, but the volumes and characteristics of the wastes generated by these fuel cycles are different. A cohesive waste classification system will be needed to define the facilities required to support waste disposal. Currently, the United States relies on an ad hoc system based on point of origin to address management of specific wastes. The result is a complex dual waste categorization system, one for defense wastes and another for civilian wastes. This approach has resulted in high disposition costs, nuclear waste with no disposition pathways, limited disposition sites, and a system that will be difficult to align with any alternative fuel cycle that is adopted. Without a consistent waste classification system, it is impossible to compare waste management costs and risks for different fuel cycles without making arbitrary assumptions regarding theoretical disposition pathways.

The International Atomic Energy Agency (IAEA) recommends a risk-based classification system that accounts for the intensity of the radiation and the time needed for decay to an acceptable level. The intensity of radiation is given by a range of radioactivity per unit of weight. Decay time is split into short lived (< 30 years) and long lived (>30 years). The IAEA system does not consider the source of nuclear waste in either categorization or disposition options. The result is a simple, consistent, standardized system.

The question of waste categorization is yet another example of why reprocessing technologies should be fully considered in any discussions about disposal options and long-term waste management policies. Alternative technologies will have different economies of scale based on the type and number of wastes. In addition, waste packages may be retrievable or not, and waste forms should be tailored to the repository site geology. Given the need to craft the most cost-effective solution, it would be a missed opportunity to approach the question of long-term disposition without developing a congruent approach to the fuel cycle.

An Effective Fuel Cycle Strategy Going Forward

Argonne believes that advanced recycle processes and waste management technologies should be developed and demonstrated at engineering scale during the next few decades. To enable an effective research and development strategy, the development of advanced fuel treatment technologies and waste forms must be closely coordinated with R&D on:

- Advanced fuels and interim storage strategies for current light water reactors (LWRs), as these affect the requirements on reprocessing and waste technologies. Research on advanced fuels for light water reactors is one of the proposed thrusts of the DOE-NE Light Water Reactor Sustainability program
- Advanced reactors such as liquid metal and gas-cooled “Generation IV” reactors, which employ different fuel types and thus discharge used fuel that is very different from that of LWRs. Advanced fast spectrum reactors can efficiently consume the residual actinides in used nuclear fuel, effectively converting these actinides to electricity instead of discharging them as waste.

Recommendations

As part of our long-term strategy for nuclear waste management, the United States should conduct an advanced nuclear fuel cycle research, development, and demonstration program to evaluate recycling and transmutation technologies that minimize proliferation risks and environmental, public health, and safety impacts. This would provide a necessary option to reprocessing technologies deployed today, and supports evaluation of alternative national strategies for commercial used nuclear fuel disposition, effective utilization and deployment of advanced reactor concepts, and eventual development of a permanent geologic repository(s). This should be done as part of robust public-private partnerships involving the Department of Energy, its national laboratories, universities, and industry; and conducted with a sense of urgency and purpose consistent with the U.S. retaining its intellectual capital and leadership in the international nuclear energy community.

Over the next several years, the research, development, and demonstration program should:

- Complete the development and testing of a completely integrated process flow sheet for all steps involved in an advanced nuclear fuel recycling process.
- Characterize the byproducts and waste streams resulting from all steps in the advanced nuclear fuel recycling process.
- Conduct research and development on advanced reactor concepts and transmutation technologies that consume recycled byproducts resulting in improved resource utilization and reduced radiotoxicity of waste streams.
- Develop waste treatment processes, advanced waste forms, and designs for disposal facilities for the resultant byproducts and waste streams characterized.
- Develop and design integrated safeguards and security measures for advanced nuclear fuel recycling processes that enable the quantification and minimization of proliferation risks associated with deploying such processes and facilities.
- Evaluate and define the required test and experimental facilities needed to execute the program.

Upon completion of sufficient technical progress, the program should:

- Develop a generic environmental impact statement for technologies to be further developed and demonstrated,
- Conduct design and engineering work sufficient to develop firm cost estimates with respect to development and deployment of advanced nuclear fuel recycling processes.
- Cooperate with the NRC in making DOE facilities available for carrying out independent, confirmatory research as part of the licensing process.

Argonne supports a greater emphasis on coupling the science-based approach for system development with an active design and technology demonstration effort that would guide and appropriately focus R&D, and thus enable assessment of programmatic benefits in a holistic manner. This would be accomplished by close cooperation of DOE, national laboratories, universities, and industry. The overall approach would seek to:

- Increase understanding of the diverse physical phenomena underlying reactor and fuel cycle system behavior.
- Improve ability to predict system behavior through validated modeling and simulation

for design, licensing; and operation.

- Develop advanced materials, processes, and designs for reactor and fuel cycle systems through application of scientific discoveries and advanced modeling and simulation capabilities, as well as the insights and lessons learned from past nuclear energy development programs.

These efforts would allow for fuel cycle demonstration in a timeframe that could influence the course of fuel cycle technology commercialization on a global basis. Moreover, each of the individual elements of the planned R&D (e.g., separations, waste forms, transmutation fuels) is potentially vast in scope and could absorb substantial resources, without commensurate benefit, if the different areas are not sufficiently integrated for the results to fit together in a viable system.

It is clear that the United States must address significant hurdles, both in policy and in technology, as we seek effective solutions to the pressing question of used nuclear fuel management. We can expect success only if we can craft a consistent national policy that includes substantial support for a robust advanced fuel cycle research and development program, to be carried out through strong public-private partnerships involving the Department of Energy (DOE), its national laboratories, universities, and industry. This program must be focused on outcomes and closely integrated with storage and disposal efforts. It also must support evaluation of alternative national strategies for commercial used nuclear fuel disposition in close conjunction with ongoing efforts to site and develop a permanent geologic repository(s). Ultimately, this program must lead to down-selection, demonstration, and deployment of effective advanced fuel cycle technologies. Only through a reasoned plan for research, development, and deployment can we expect to reach a wise, workable decision on a preferred fuel cycle technology that will enable safe and sustainable expansion of the U.S. nuclear fleet.