Repositories and National Programs
Fuel Cycle Research and Development Program, Used Fuel Disposition Campaign
Objective, Mission, Plans, and Activity Status

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ABSTRACT

The safe management and disposition of used nuclear fuel and/or high level nuclear waste is a fundamental aspect of the nuclear fuel cycle. The United States currently utilizes a once-through fuel cycle where used nuclear fuel is stored on-site in either wet pools or in dry storage systems with ultimate disposal in a deep mined geologic repository envisioned. However, a decision not to use the proposed Yucca Mountain Repository will result in longer interim storage at reactor sites than previously planned. In addition, alternatives to the once-through fuel cycle are being considered and a variety of options are being explored under the U.S. Department of Energy’s Fuel Cycle Research and Development Program. These two factors lead to the need to develop a credible strategy for managing radioactive wastes from any future nuclear fuel cycle in order to provide acceptable disposition pathways for all wastes regardless of transmutation system technology, fuel reprocessing scheme(s), and/or the selected fuel cycle. These disposition paths will involve both the storing of radioactive material for some period of time and the ultimate disposal of radioactive waste.

To address the challenges associated with waste management, the DOE Office of Nuclear Energy established the Used Fuel Disposition Campaign within its Fuel Cycle Research and Development Program in the summer of 2009. The mission of the Used Fuel Disposition Campaign is to identify alternatives and conduct scientific research and technology development to enable storage and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles. The near- and long-term objectives of the Fuel Cycle Research and Development Program and it’s Used Fuel Disposition Campaign are presented.

NUCLEAR ENERGY RESEARCH AND DEVELOPMENT

To achieve energy security and greenhouse gas emission reduction objectives, the United States must develop and deploy clean, affordable, domestic energy sources as quickly as possible. Nuclear power will continue to be a key component of a portfolio of technologies that meet our energy goals. The U.S. Department of Energy’s Office of Nuclear Energy (DOE-NE) recently developed a roadmap of its research, development and demonstration (RD&D) activities that will ensure nuclear energy remains a compelling and viable energy option for the United States.

As shown in Figure 1, DOE-NE has organized its RD&D activities according to four objectives that address the challenges to expanding the use of nuclear power. The objectives are:

(1) Extend life, improve performance, and maintain the safety of the current fleet;
(2) Enable new plant builds for electricity production and improve the affordability of nuclear energy;

(3) Enable the transition away from fossil fuels by producing process heat for use in the transportation and industrial sectors;

(4) Enable sustainable fuel cycles; and

(5) Understand and minimize proliferation risk.

To achieve a sustainable fuel cycle there are three primary aspects that need to be considered:

1. Availability of fuel resources,
2. Adequate capability and capacity to manage all the nuclear wastes produced by the fuel cycle, and
3. Improving utilization of fuel resources while minimizing the generation of nuclear waste.

Figure 1. Five imperatives for nuclear energy research and development
A principal challenge for the government in the fourth imperative is to develop a suite of options that will enable future decision-makers to make informed choices about how best to manage the used fuel from reactors. An expansion of nuclear power in the United States will result in a growth of the used nuclear fuel inventories. The Nuclear Waste Policy Act of 1982 gave the U.S. Government the mission to safely manage the used fuel from these nuclear power plants. This management will require the safe storage of used fuel for some length of time prior to disposal or treatment. The extent to which the used fuel is further processed to remove key elements from the waste for reuse will define the nuclear fuel cycle and the wastes that will require disposal. In addition to the used fuel and high-level waste that will contain most of the highly-radioactive elements, secondary waste or byproducts including low-level waste, and depleted uranium will require safe management and disposition.

The DOE-NE RD&D strategy for used fuel management is to investigate the technical challenges that would be encountered in each of three strategies that may be deployed in the future and develop technologies that could demonstrate the best approach within each of these strategies:

- **Once-Through Fuel Cycle** – Nuclear fuel makes a single pass through a reactor after which the used fuel is removed, stored for some period of time, and then directly disposed in a geologic repository for long-term isolation from the environment. The used fuel will not undergo any sort of treatment to alter the waste form prior to disposal in this approach, eliminating the need for separations technologies that may pose proliferation concerns. Less than one percent of the mined uranium is utilized in the present once-through fuel cycle.

- **Modified Open Cycle** – The goal of this strategy is to develop fuel for use in reactors that can increase utilization of the fuel resource and reduce the quantity of actinides that would be disposed in used fuel. This strategy is “modified” in that some limited fuel processing technologies, perhaps including separation, are applied to the used LWR fuel to create fuels that enable the extraction of much more energy from the same mass of material and improve waste management characteristics.

- **Full Recycle** – In a full recycle strategy, all of the actinides important for waste management are recycled in thermal- or fast-spectrum systems to reduce the radiotoxicity of the waste placed in a geologic repository while more fully utilizing uranium resources. In a full recycle system, only those elements that are considered to be waste (primarily the fission products) would be disposed, not used fuel. Implementing this system will require extensive use of separation technologies.

In all of these strategies, depicted in Figure 2, new reactor technologies may be introduced that would appreciably alter the sustainability of the strategy. Once the RD&D is sufficiently advanced, perhaps twenty or thirty years from now, decision-makers will have sufficient information to decide which of the approaches are best suited for demonstration. As a target, the DOE-NE RD&D effort is guided by the goal of enabling a national decision to deploy a chosen waste management system by 2050.
THE FUEL CYCLE RESEARCH AND DEVELOPMENT PROGRAM

The DOE-NE Fuel Cycle Research and Development Program (FC R&D) is investigating future nuclear fuel cycles, in particular a sustainable fuel cycle. The FC R&D Program will provide a more complete understanding of the underlying science supporting the development of advanced fuel cycle technologies and, there, provide a sound basis for any future decisions on the U.S. nuclear fuel cycle.

The Mission of the FC R&D Program is:

To develop options to current commercial fuel cycle management strategy to enable the safe, secure, economic, and sustainable expansion of nuclear energy while minimizing proliferation risks by conducting research and development focused on nuclear fuel recycling and waste management to meet U.S. needs.

The Objectives of the FC R&D Program aim to develop a sustainable fuel cycle by:

1. Developing options for used nuclear fuel management that reduce the long-term environmental burden
2. Enhancing overall nuclear fuel cycle proliferation resistance via improved technologies for used fuel management
3. Enhancing energy security by extracting energy recoverable in used fuel, thus extending uranium resources
4. Continuing to improve fuel cycle economics and the excellent safety performance of the entire fuel cycle system.

A dual-path approach will be applied to achieve the goal of developing and demonstrating sustainable fuel cycle options in the long-term. The approach is comprised of defining and pursuing R&D pathways in seven critical technical areas along with the application of the discipline of systems engineering at a programmatic level to define, evaluate, and eventually develop integrated fuel cycle system solutions for demonstration and validation. The research pathways are:

- Fuel Resources
- Fuels
- Separations
- Waste Forms
- Storage and Disposal
- Transmutation Technologies (including advanced reactors)
- Materials Protection, Control and Accountability

Working in an environment of limited resources and aging infrastructure, a new approach to research and development is being used with new partnerships allied with new methods and new technologies. Taking advantage of recent advances and experiences in government and industry in the use of modeling and simulation (including high-performance computing) and small-scale experiments, the FC R&D Program will conduct science-based research and development that integrates theory, experiment, and high performance modeling and simulation to develop the needed technologies. These technologies must exceed current safety and security standards; minimize the long-term environmental and proliferation risks of used fuel, and ultimately support the electric utility industry as they deliver economic electrical power to competitive markets.

There are six principal criteria that should be used to evaluate the desirability of a fuel cycle: nuclear waste management, resources, proliferation risk, safety, security, and economics. There are other criteria that will also be defined and evaluated, for example technical maturity as part of the process of providing decision makers with the information needed to determine which fuel cycle options will be developed and demonstrated. The relative importance of an individual criterion against the others may well be viewed differently by different stakeholders, but from this nascent stage of discovery all need to be considered.

THE USED FUEL DISPOSITION CAMPAIGN

The FC R&D has established the Used Fuel Disposition Campaign to conduct the R&D activities related to storage and disposal. The mission of the Used Fuel Disposition Campaign is to identify alternatives and conduct scientific research and technology development to enable storage and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles.

The safe management and disposition of used nuclear fuel and/or high level nuclear waste is a fundamental aspect of the nuclear fuel cycle. The United States currently utilizes a once-through fuel cycle where used nuclear fuel is stored on-site in either wet pools or in dry
storage systems with ultimate disposal in a deep mined geologic repository envisioned. However, a decision not to use the proposed Yucca Mountain Repository will result in longer interim storage at reactor sites than previously planned. In addition, alternatives to the once-through fuel cycle are being considered as discussed above. These two factors lead to the need to develop a credible strategy for managing radioactive wastes from any future nuclear fuel-cycle in order to provide acceptable disposition paths for all wastes regardless of transmutation system technology, fuel reprocessing scheme(s), and/or the selected fuel cycle. These disposition paths will involve both the storing of radioactive material for some period of time and the ultimate disposal of radioactive waste. As disposition paths evolve from the continuing research and development process, it is important that storage options for fuel cycle materials remain as flexible as possible in order to facilitate selected disposal options.

While considerable progress has been made in the development and optimization of storage systems for managing used nuclear fuel used in the current light water reactor (LWR) fleet, the investment in additional research and development could lead to more robust systems having improved security aspects, resulting in further improvements in the management of LWR used nuclear fuel. The FC R&D Program has been directed to assess such alternative technologies. Advanced transmutation systems will utilize fuels, and possibly targets, that are quite different than LWR fuel. Research will be needed to identify and develop practical storage systems for these materials, leveraging on the experience gained for developing LWR used fuel storage systems.

The disposal of radioactive waste of all classifications (low-, intermediate-, high-level waste, and used nuclear fuel) has been investigated world-wide since the inception of nuclear power. While significant progress has been made regarding disposal, the routine disposal of used nuclear fuel and radioactive waste remains problematic. Experience with the Yucca Mountain Project has illustrated the challenges of siting, characterizing, designing, and licensing a geologic repository. Progress has been demonstrated by the deployment of near-surface disposal facilities for low level waste and the Waste Isolation Pilot Plant for the disposal of defense-related transuranic wastes. However, the capacity for disposing of low level wastes is limited, potential disposal pathways for Greater Than Class C low level waste (which is essentially intermediate level waste) have yet to be identified, and the disposal of used nuclear fuel and high level waste has not been demonstrated. An expansion of nuclear power in the United States, and world-wide, and the closing of the nuclear fuel cycle would increase the amount of all classes of waste and requires the availability of routine disposal pathways.

Recognizing that the current system for managing nuclear waste is viable for several decades, the Used Fuel Disposition Campaign has established five near-term objectives and four long-term objectives; in turn, these objectives support achievement of FC R&D Program objective II-1: stated above:

Near-Term Objectives

1. Provide technical expertise to inform policy decision-making regarding the management of used nuclear fuel and radioactive waste that would be generated under existing and potential future nuclear fuel cycles, in collaboration with the DOE offices of Civilian Radioactive Waste Management and Environmental Management
2. Develop a comprehensive understanding of the current technical bases for storing used nuclear fuel and high-level nuclear waste to identify opportunities for long-term research and development
3. Develop a storage roadmap that provides viable options to long-term storage of used nuclear fuel and high-level nuclear waste that incorporates a systems perspective of fuel cycle alternatives.

4. Develop a comprehensive understanding of the current technical bases for disposing of used nuclear fuel, low-level nuclear waste, and high-level nuclear waste in a range of potential disposal environments to identify opportunities for long-term research and development.

5. Model development for the evaluation of disposal system performance in a variety of generic disposal system concepts.

**Long-Term Objectives**

1. Develop a fundamental understanding of the performance of potential storage system concepts over many decades for a variety of used nuclear fuel types and radioactive waste forms based on simulation and experiment.

2. Initiate long-term storage strategies through a small-scale demonstration project that incorporates the technologies identified and developed from the near-term storage objectives.

3. Develop a fundamental understanding of disposal system performance in a range of environments for potential wastes that could arise from future nuclear fuel cycle alternatives through theory, simulation, testing, and experimentation.

4. Develop a computational modeling capability for the performance of storage and disposal options for a range of fuel cycle alternatives, evolving from generic models to more robust models of performance assessment. Ensure Nuclear Energy Advanced Modeling and Simulation (NEAMS) activities are well-integrated so that improved system level models are realized.

Within the FC R&D Program, the Used Fuel Disposition Campaign is intimately linked with the Separations and Waste Form Campaign because that campaign is investigating the possible waste forms that could be used to isolate wastes generated under alternative fuel cycles and developing modeling capabilities for their long-term performance in disposal system environments. The Used Fuel Disposition Campaign is also linked with the Systems Analysis Campaign by providing that campaign with information for evaluating waste management impacts within fuel cycle system analyses. Lastly, as discussed above, the Used Fuel Disposition Campaign will work in collaboration with the Nuclear Energy Advanced Modeling and Simulation program in the development of advanced modeling tools for evaluating disposal system performance.

The Used Fuel Disposition Campaign will also interface with the DOE office of Environmental Management because there is considerable commonality in issues and needed modeling capability among the three organizations.

The Used Fuel Disposition Campaign will also involve collaboration with universities, the U.S. Nuclear Regulatory Commission, and the nuclear industry. Their experience, knowledge, and expertise is essential in establishing future strategies and approaches for the management of nuclear wastes in the U.S.

The management of nuclear waste has also been investigated internationally. A wealth of information and knowledge is available, in particular regarding disposal environments that have not been under consideration in the U.S. for a number of years. The Used Fuel Disposition Campaign will participate extensively with international working groups and already...
collaborates with Japan through a bilateral agreement. Additional international collaborations will be pursued through existing and potential future frameworks.

KEY BARRIERS AND TECHNICAL CHALLENGES

Storage

Neither wet nor dry storage systems offer a permanent solution for managing used nuclear fuel or high level nuclear waste. Rather, they are designed to be temporary with plans for the ultimate removal of the material and subsequent disposition (i.e., disposal). The unavailability of disposition options, such as a permanent disposal facility, has resulted in the potential for needing an extended storage period. Dry used fuel storage systems are typically licensed by the U.S. Nuclear Regulatory Commission for a 20-year period, although extended storage for periods of up to 60 years has been licensed. Storage for even longer may be viable, although research and development is needed to determine how long storage may be technically feasible.

Current storage policy is that the status quo is acceptable for long-term storage pending a decision on fuel cycle alternatives and final disposal. This is a reasonable approach based on current economics, a stable regulatory environment, and sufficient land space to expand the on-site storage footprint, as needed. From a longer term strategic perspective, several issues arise that will need to be addressed:

- As UNF continues to be stockpiled in long-term storage, on-site storage space may become limited and there may be a drive to interim storage of UNF at one or more consolidated, independent used fuel storage facilities,
- The NRC is going into rule-making regarding waste confidence and also security requirements for UNF storage,
- There is a general security concern regarding this increasing stockpile of stored UNF at many different reactor sites,
- Stranded fuel (i.e., fuel that is stored at shut-down reactor sites) will need to be managed from a more unified perspective, as opposed to the current ad hoc manner, and
- Utilities are going to higher burnup fuels that will require additional safety and security assessments to verify their compatibility for storage under current regulatory and operational regimes, and validation requirements for UNF integrity for shipment after long term storage need to be developed.

Disposal

When considering the safety of disposal systems, the fundamentals of radiation protection are translated to two primary considerations.

- Completely isolating disposed wastes for as long as possible, after which:
- Limiting radionuclide releases to the accessible environment where radiation exposure could occur.