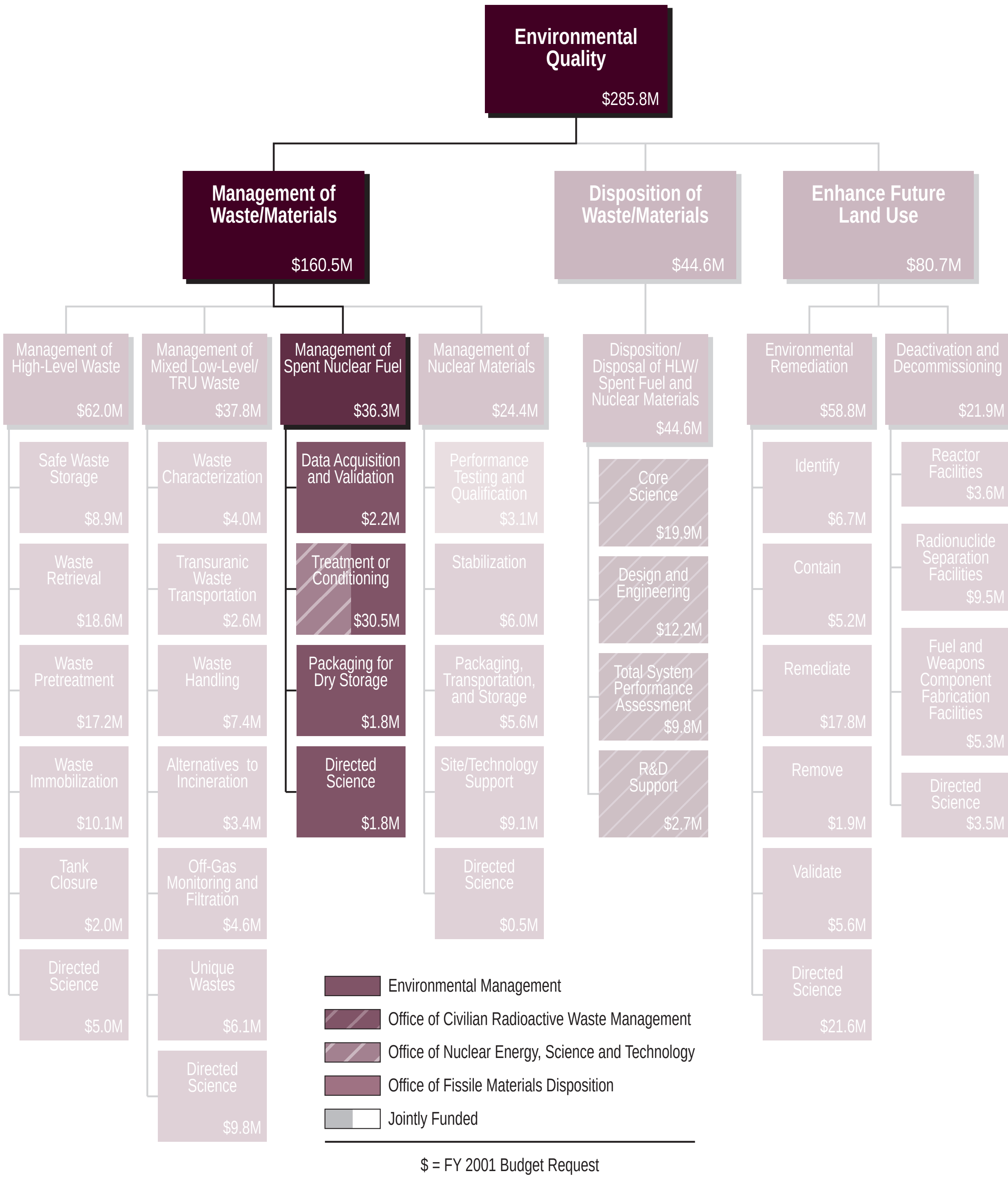
Chapter 5
Spent Nuclear Fuel



Chapter 5

Spent Nuclear Fuel

Table of Contents

Overview

Definition of Problem Area

The U.S. operated 14 nuclear reactors between 1944 and 1988 to produce plutonium and tritium for nuclear warheads. In addition, the U.S. operated many other test reactors to encourage and support both commercial and military reactor developments. During that time, most of the nuclear fuel rods and targets irradiated in the reactors were reprocessed to extract the plutonium as well as the leftover enriched uranium for reuse. In addition, the US Navy operated many nuclear propulsion reactors, from which the fuel assemblies were processed to recover and reuse the remaining fissile uranium. These fuel rods, targets, and assemblies are referred to as spent nuclear fuel (SNF). The Department's spent fuel is not categorized as waste, but is highly radioactive and must be stored in special facilities that shield and cool the material. Most spent fuel is stored in indoor pools under water, although some spent fuel is kept in dry storage.

The Idaho National Engineering and Environmental Laboratory (INEEL), the Savannah River Site (SRS), and the Hanford Site generated and now manage most of the existing SNF in the DOE complex. Prior to 1992, most DOE SNF was dispositioned through reprocessing. In 1992, DOE began to phase out reprocessing operations. In 1995, DOE decided upon a planning basis that identified disposal of DOE SNF in the first geologic repository. Since then, deliberations have determined a need to articulate the requirements that must be met in order for DOE SNF to be accepted in the repository. The safe, reliable, and efficient management of DOE SNF and preparation for its final disposition is a major challenge due to the multiple sites involved and the wide variety of SNF types.

In June 1995, a Record of Decision (ROD) was issued for the Programmatic SNF Management Environmental Impact Statement. This ROD, defined the path forward for the management (40-year period) of DOE SNF as regionalization by fuel type. Under this path, as modified by the Idaho Settlement Agreement, SNF management occurs at three primary sites until a geologic repository is opened. The sites are Hanford, INEEL, and SRS. The fuel type distribution is: Hanford fuel will remain at its present location with the exception of its sodium-bonded fuel, which will be transported to the INEEL for treatment; aluminum clad fuel will be consolidated at the SRS; and non-aluminum clad fuels (including the Naval SNF, but excluding the Fort St. Vrain (FSV) SNF, which will be safely maintained at its present location in Colorado) will be transferred or retained at the INEEL.

Hanford Site - Over 2,100 metric tons heavy metal (MTHM) of SNF are currently in inventory. [MTHM refers primarily to uranium metal, but also includes plutonium where present.] After washing, packaging, and drying, this SNF will be transferred to dry storage until shipment either to a repository or to an alternative treatment system.

Idaho National Engineering and Environmental Laboratory - Approximately 60 MTHM of SNF will be received from off-site sources. Currently, there are 270 MTHM (640 cubic meters) of SNF in inventory. This quantity includes the 0.8 MTHM in spent graphite fuel located at a dry storage facility in Fort St. Vrain, Colorado managed by the INEEL. After on-site storage, drying, and packaging, all SNF is expected to be shipped off-site to a repository for disposal.

Savannah River Site - Approximately 20 MTHM of SNF are in inventory and 30 MTHM of spent fuel are expected to be received from off-site sources. The spent fuel is expected to be prepared and placed in an off-site geologic repository.

The estimated costs for management and preparation for disposal of DOE's SNF are shown in Figure 5-1.

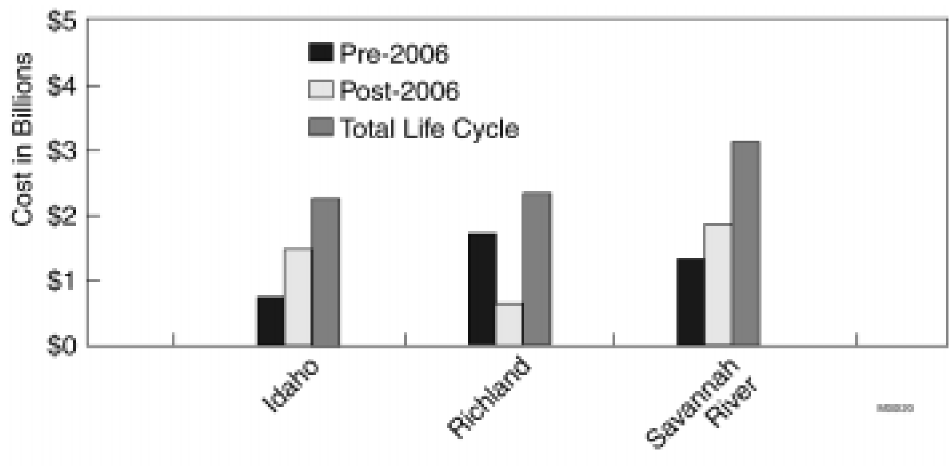


Figure 5-1. Through 2006, Post-2006, and Life Cycle costs for managing spent nuclear fuel.

National Context/Drivers and Federal Role

The Spent Nuclear Fuel investment area generally addresses the need to dispose of the Nation's nuclear legacy, by disposing of a wide range of spent nuclear fuel generated from 1) nuclear power and other commercial and industrial uses, 2) weapons development and nuclear propulsion for national security, and 3) nuclear research and test reactors. End states for DOE spent nuclear fuel include two features: safe and effective interim storage prior to final disposition, followed by shipment of prepared SNF to a Monitored Geologic Repository (MGR). The MGR is scheduled to be opened in 2012, whereupon, DOE SNF shipments will begin, and will continue routinely until completed at about 2035. At the MGR, SNF is to be inserted into waste disposal packages and be placed in geologic strata, while maintaining a retrieval capability for up to 100 years. The Office of Civilian Radioactive Waste Management (OCRWM) will maintain the repository, conduct monitoring, and defer a final decision on repository closure for up to 300 years.

The United States also has growing inventories of spent nuclear fuel from commercial nuclear power reactors, currently stored at reactor sites in 33 states, and spent fuel from nuclear-powered naval vessels. Geologic disposal is the national strategy for the ultimate disposition of spent fuel and of defense high-level radioactive waste. It is also the technical foundation for the international stance on nuclear nonproliferation, as well as the likely path forward for other materials such as excess fissile materials. Figure 5-2 shows the SNF disposition process.

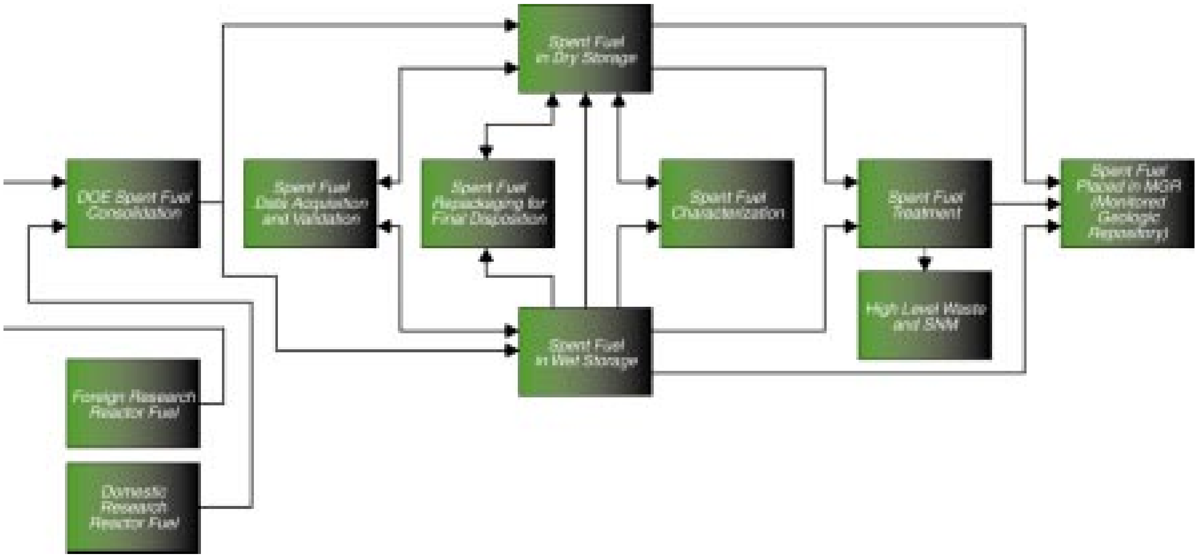


Figure 5-2. Pathway for SNF disposition to a monitored geologic repository.

Linkage to DOE Strategic Goals and Objectives

The spent nuclear fuel activities support and impact the environmental quality strategic objectives at the levels indicated in Figure 5-3.

The primary focus of spent nuclear fuel activities is an Environmental Quality strategic objective, "Dispose or treat spent nuclear fuel in accordance with the Nuclear Waste Policy Act (NWPA) as amended." Two strategies have been outlined to achieve this objective: (1) complete the scientific and technical analyses of the Yucca Mountain site, and if it is determined to be suitable for a geologic repository, obtain a license from the Nuclear Regulatory Commission (NRC); (2) maintain the capability to rapidly respond to potential statutory direction that may include transportation of spent nuclear fuel and high-level waste to a designated interim storage facility.

Each of the SNF projects has particular needs related to the type(s) of fuel and storage configurations at site. The major objectives in each case are to mitigate existing risk sources, establish and maintain safe interim storage conditions, and prepare for final geologic disposition. Positioning the SNF in safe interim dry storage is a primary and immediate objective, well in advance of the MGR.

- Hanford Site: In accord with a tri-party agreement, N-reactor spent fuel will be transferred expeditiously from existing wet-basin storage into a new dry storage facility. The SNF will be stored dry in multicanister over packs (MCO) until MGR shipment.

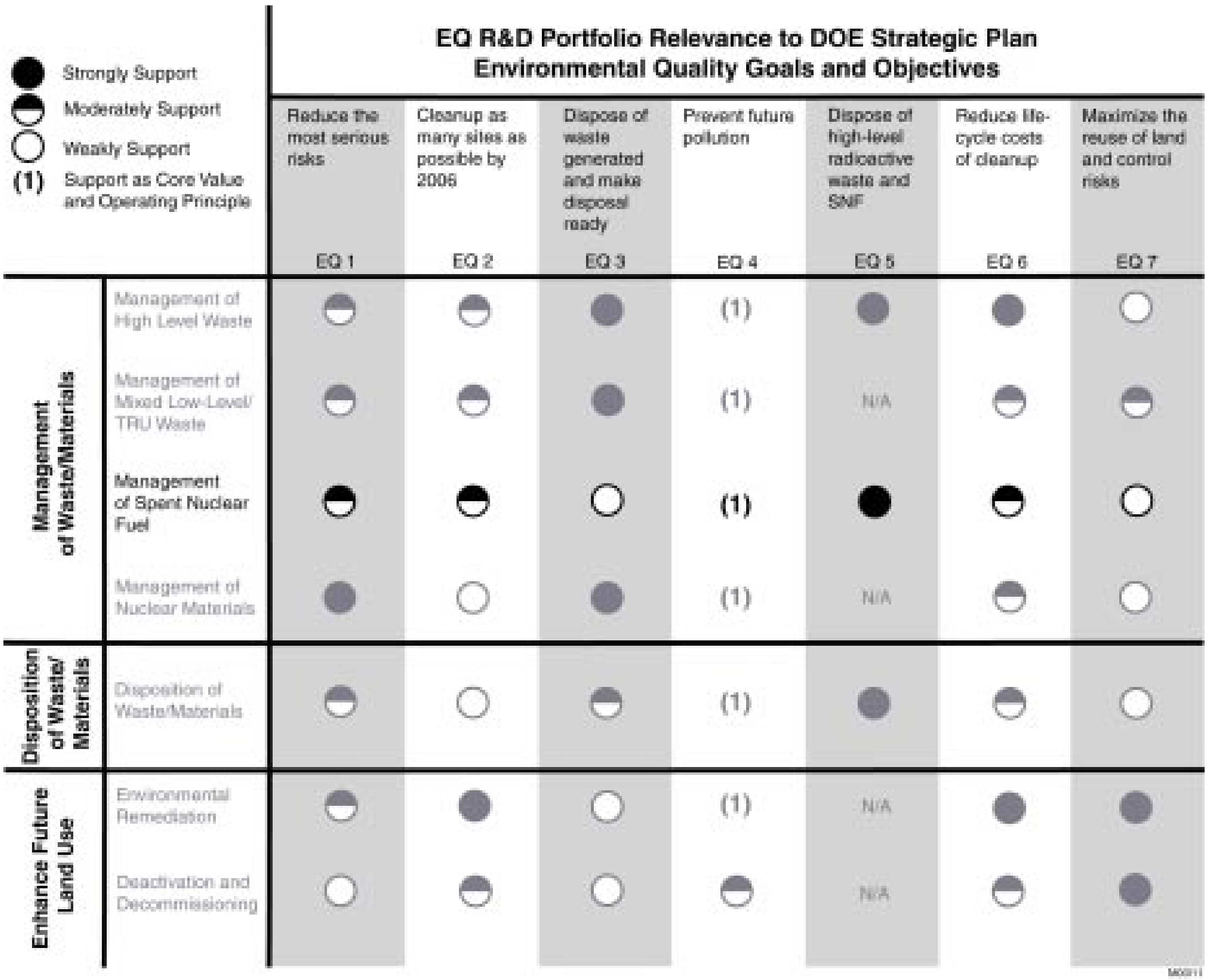


Figure 5-3. Relevance of spent nuclear fuel R&D investments to Environmental Quality goals and objectives.

- INEEL: In accord with a joint agreement with the State of Idaho and the US Navy, INEEL spent nuclear fuel will be transferred from existing wet basins over the next several years, and will be stored in road ready canisters in dry storage facilities awaiting shipment to the MGR, beginning in 2012 and being completed by 2035.

- Savannah River Site: Stored SNF, primarily aluminum based, will be either treated and or dry stored prior to MGR shipments. The preferred path is treatment of the aluminum based SNF to dilute the enriched uranium and to increase the criticality safety, followed by dry storage until MGR shipment.

Problem Area Uncertainties

The Department has made substantial progress in characterizing Yucca Mountain, Nevada, to determine its suitability as a geologic repository site for spent fuel and other long lived wastes. However, DOE continues to face substantial political opposition and legal challenges in implementing its waste disposal mandate under the NWPA, as amended. Waste acceptance criteria for SNF to be shipped to the MGR have been studied at length, but final form is uncertain, and probably cannot occur prior to NRC licensing of the geologic facility. Thus, some potential for change exists, which can then change the direction and magnitude of research and development leading to disposal of DOE SNF. There exist over 250 types of SNF, many of these being unique and one-of-a-kind SNF designs. The obvious differences will require considerable efforts into SNF characterization and repository bounding performance analyses. In addition to identified uncertainties, there remains the continued downward pressure on funding, which increases the uncertainty of a timely and successful conclusion.

R&D Investment Trends and Rationale

Figure 5-4 illustrates the current R&D investments for spent nuclear fuel management.

Figure 5-4. Cumulative investment in spent nuclear fuel areas over 3 years (FY 1999–FY 2001).

In accordance with DOE policy, SNF which meets OCRWM acceptance criteria will be directly disposed into the first geologic repository at Yucca Mountain if it is found suitable as a geologic repository. The few exceptions to this policy are for specific SNF that is at risk during the expected long interim storage period (up to 40 years), and for sodium-bonded fuels. Although the remaining fuel types appear ready for MGR disposition, deliberations within the Department have determined a need to articulate the requirements that must be met in order for DOE SNF to be accepted in the repository. Thus, the technology needs, as identified by the SNF storage sites, span a full range of basic research (e.g., MGR release rates of unique SNF types) to implementation (e.g., nondestructive assay systems to examine SNF cans/canisters).

Although acceptance and transportation of DOE SNF to a MGR is not programmed to begin until 2012 AD at the earliest, significant SNF data and treatment paths are needed much sooner, to ensure safe storage and meet state and DOE settlement agreements, and to support MGR performance studies and licensing activities. Thus, early investment into research and development activities is necessary earlier than at first perceived, based on MGR scheduled availability. This early development is evident in Table 5-1, where development needs are higher in the first five-year period. In addition, development efforts always carry some risk of failure, which may be mitigated either by parallel or sequential alternative development. Evident downward pressures on available funding sources require acceptances of higher risks at earlier stages of development; and if development failure were to occur, as has happened previously, it could result in increased costs as program deadlines draw closer.

Table 5-1. Cumulative investment needs for spent nuclear fuel areas over 5 years and 10 years (dollars in millions).

DOE SNF Site	Five-Year Investment Needs,	Ten-Year Cumulative
ANL-W	35	45
Hanford Site	14	18
INEEL	28	49
Savannah River Site	100	119

Key R&D Accomplishments

The National Spent Nuclear Fuel Program has, in concert with the major SNF storage sites, identified disposal paths and alternatives for nearly all fuel types now in the inventory, and is working on requirements and specifications for DOE SNF disposition in a proposed MGR.

Transportation of many SNF types into improved extended-term dry storage facilities has been initiated.

Acceptance of all EM SNF types into RW MGR licensing and performance analyses has been achieved, with a few exceptions of some having chemical reaction or waste hazards.

The Savannah River site and the INEEL have begun receiving shipments of up to 250 spent nuclear fuel elements from foreign research reactors. The elements, which contain highly enriched uranium of U.S. origin, are being accepted to uphold the Nation's nuclear weapons nonproliferation policy.

Key R&D Issues

The safe management, storage, and geologic disposition of SNF requires solutions to key R&D issues:

- Treatment methodologies for sodium-bonded SNF (Hanford and INEEL) and aluminum-clad SNF (SRS), and others as needed.
- Drying and conditioning processes to allow removal of SNF from basin storage to extended-interim dry storage.
- Safe dry storage of characterized SNF.
- Development of performance models for criticality, heat-transfer, radionuclide source terms, etc., for all fuel types in dry storage and at the repository.
- Determination of degradation rates and corrosion product characteristics for all SNF and treated forms in interim dry storage and the repository.
- Non-destructive assay (NDA) and non-destructive examination (NDE) systems to assist with characterization and certification of SNF, treated forms, and acceptance criteria data (either during or after dry storage).

Problem Area R&D Program

Budget: FY99-$48.5M, FY00-$33.7M, FY01-$36.3M

Program Description

The key technical need areas within the program are SNF data acquisition and validation, packaging for dry storage, and treatment or conditioning (if needed). Directed science research supports these three technical development areas.

Data Acquisition and Validation

Budget: FY99-$1.1M, FY00-$1.6M, FY01-$2.2M

Description, Objectives, and Performers. Data specific to each of over 200 types of DOE SNF is needed prior to certification of the fuel for the MGR. Since many of the DOE SNF types are from one-of-a-kind reactors or reactor fuel experiments and from post-irradiation examinations performed many years ago, the available data quality may not meet the more stringent standards of the present day. For the SNF to be accepted for safe, permanent MGR disposal, fuel data must be certified and qualified prior to SNF shipment from present storage and management sites. Each site will have a significant program for gathering the available data, and for assuring the data's accuracy and qualification.

R&D Challenges. Investments are needed in two areas: one, to determine the necessary pedigree required to "qualify" existing fuel data, and two, in systems for qualifying all data related to DOE SNF types including assembling original manufacturer data and drawings, reactor history, post-irradiation examinations, fissile loading, burnups, storage since reactor withdrawal, fuel quantities, fuel matrix, etc. In order to qualify the SNF data, new systems for NDA/NDE may need to be developed. Development of systems to determine dryness and hydrogen content of SNF packages may also be needed. Methods for determining the integrity of the fuel and storage package will be needed to eliminate the need for repackaging prior to MGR shipment.

R&D Activities: Activities include development of new NDA/NDE systems that can independently verify existing SNF values, e.g., fissile quantities, key radionuclide quantities, and fuel integrity.

Accomplishments:

- Establishment of the National Spent Nuclear Fuel Program fuel database.
- Reports compiled on individual fuel types.
- Reports on capabilities and level of development of existing NDA systems.
- Identification of Multi Detector Array system (MDAS) as a most promising NDA system along with its potential capabilities.
- Reports on characterization requirements for aluminum SNF.

Treatment or Conditioning

Budget: FY99-$44.4M, FY00-$28.1M, FY01-$30.5M

Description, Objectives, and Performers. In some cases the spent fuel may require conditioning or treatment to prepare it for disposal or long-term storage. For example, damaged fuel may need to be conditioned or repackaged to reduce risks. Some fuel types (e.g. sodium-bonded) may contain constituents that are not acceptable at the MGR. Also, spent fuel containing highly enriched uranium may require dilution treatment to avoid potential security and criticality problems during storage or after disposal.

An integrated program is being conducted to develop and evaluate an electrometallurgical treatment technology. This will enable the Department in mid FY-2000 to reach a record of decision on proposed actions to treat EBR-II fuel, and possibly other sodium-bonded fuel, in Idaho. The electrometallurgical treatment technology is a by-product of the unique capabilities developed at Argonne National Laboratory in their support of the Department's Integral Fast Reactor (IFR) and other liquid metal reactor research programs. This treatment technology employs electrorefining techniques to convert spent nuclear fuel into two compact waste forms. This R&D will also help the Department decide on future development of the technology for the treatment of other types of DOE spent fuel. The waste form R&D will provide data to ensure and support ultimate disposition of the electrometallurgical waste forms in a geologically mined repository.

A melt-dilute treatment technology program is focused on the development and implementation of a treatment technology for diluting highly enriched (>20% ^{235}U) aluminum spent nuclear fuel to low enriched levels (<20% ^{235}U) and qualifying the LEU Al-SNF form for geologic repository storage. In order to reduce the enrichment of these assemblies prior to ultimate geologic repository disposal, the melt-dilute technology proposes to melt these SNF assemblies and then dilute with additions of depleted uranium. The benefits accrued from this treatment process include the potential for significant volume reduction, reduced criticality potential, and the potential for enhanced SNF form characteristics. The emphasis within the development program to date has been on determining the process metallurgy and off-gas system design for the treatment of all types of Al SNF (UAl_x, Al-U_3O_8, and Al-U_3Si_2).

R&D Challenges. Investments are needed to complete the development and validation of processes for conditioning/treating specific fuel types, e.g., Na-bonded, small-lot scrap, disrupted fuel, and melt-dilute for aluminum clad SNF.

Disposal of the Experimental Breeder Reactor-II (EBR-II) fuel presents a challenging waste management problem. The presence of the sodium makes this spent fuel unique. Sodium metal is highly reactive; it reacts rapidly in air and will react violently in water. Because the sodium is partially absorbed by the uranium fuel elements, mechanical means may not be fully effective in removing it. Therefore, conservative management assessments indicate this fuel will have to be treated to a waste form acceptable in long-term disposal in a geologic repository. Other DOE spent nuclear fuels may also require treatment prior to long-term disposal.

Disposal of highly enriched Al-SNF in a geologic repository is challenging due to the criticality and proliferation concerns. A dilution treatment process was identified as the most promising alternative.

R&D Activities. Development and implementation of an Al-based SNF melt-dilute process at the SRS. Development and implementation of electrometallurgical treatment of Na-bonded SNF at ANL-W. Development of an epoxy removal technique for metallographic samples from post-irradiation examination of SNF.

Accomplishments:

The technology demonstration at ANL-W applied electrometallurgical technology to the treatment of a limited quantity of EBR-II spent fuel (about 6.25 % of the EBR-II SNF inventory), to help DOE evaluate whether it should be used to convert sodium-bonded metal fuels into durable ceramic and metal waste forms. Electrometallurgical treatment R&D supports the integrated programs to disposition DOE sodium-bonded SNF by providing experimental data, modeling and analyses needed for full process integration, and resolution of technical challenges expected during the transition to treatment operations. These R&D activities are also being used to help the Department reach a record of decision on proposed actions to treat EBR-II fuel, and possibly other sodium-bonded SNF.

- Issued the Draft Environmental Impact Statement for the Treatment and Management of Sodium-Bonded Spent Nuclear Fuel in July, 1999.
- Successfully met or exceeded during 1999, all four key electrometallurgical treatment technology demonstration criteria – treatment throughput rate, product stream quantification, process reliability, and nuclear material accountancy and regulatory compliance.
- Issue in 2000 the Record of Decision and Final Environmental Impact Statement for the Treatment and Management of Sodium-Bonded Spent Nuclear Fuel on the future use of electrometallurgical treatment.
- Continue R&D activities to support high-throughput treatment of sodium-bonded SNF, including optimization of operating parameters, and process and model development to improve equipment operation, integration and reliability.
- Continued waste form durability testing, performance assessment modeling, and repository qualification plan development.
- Conduct long-term tests to characterize performance and support license applications and regulatory acceptance of reference waste forms.

Definition of the technical bases for the Melt-Dilute Treatment Technology at the SRS was achieved through several technical activities:

- Demonstrate the versatility of technology to treat the major types of Al-bases DOE SNF-UAL_X, U_3Si_2, and U_3O_8.
- Define the optimum treatment cycle and basis to include melt time, melt temperature, alloy, composition, batch size, casting technique, furnace type, and atmosphere conditions.
- Develop the fundamental requirements for the treatment technology off-gas system by defining absorber bed materials, flow rates, volatile radionuclides, radionuclide release fractions, and disposition options for off-gas secondary wastes.
- Identify pre- and post-treatment materials characterization strategies to satisfy DOE-RW Draft Waste Acceptance Criteria.
- Develop a full-scale (1 MTR Batch Size) Melting Apparatus for treatment technology and off-gas system development.
- Develop an MD integrated process with depleted uranium surrogate fuels.

Treatment and conditioning of INEEL SNF was advanced through epoxy studies and drying tests.

- Performed prototype testing of thermal process for epoxy treatment.
- Completed a campaign of vacuum drying aluminum-plate and uranium-zirconium-hydrate fuel as removed from wet basin storage.
- Completed initial tests and first drying cycle using an elevated temperature vacuum process on canisters containing TMI-2 debris.

Packaging for Dry Storage

Budget: FY99-$0.9M, FY00-$1.7M, FY01-$1.8M

Description, Objectives, and Performers: Extended, interim, dry storage of SNF is the preferred path for safe management of DOE SNF until shipment to the MGR. At present, most SNF is or has been stored in water basins. In some of these basins, measurable corrosion of the SNF has occurred. Movement of all SNF into dry storage will limit or eliminate potential corrosion mechanisms. For some SNF, repackaging will be needed to ensure containment during the extended storage period. Since the SNF may be in storage for periods up to 30 years or more, assurance must be made the SNF will be manageable prior to MGR disposition.

Because spent nuclear fuel varies appreciably in type, quantity, form, radioactivity and condition, the fuels must be characterized before they are disposed of in the repository. Data needs are being developed by affected DOE organizations for the characterization of more than 250 types of DOE spent fuel. (Because of its classified nature, the Navy will characterize its own spent fuel, and will provide DOE with their analyses). Due to age, degradation, or specific type, some DOE spent fuels may require conditioning or stabilization before they can be accepted for disposal. A determination of the appropriate "data needs" for these conditioned/treated forms is necessary. Use of a consensus code approved test method or test protocol would be beneficial.

R&D Challenges. Investments are needed to determine packaging requirements to ensure safe dry storage for periods up to 40 years. Packaging must maintain adequate SNF integrity, prevent undue corrosion, and be able to be adequately monitored throughout the dry storage period. It also would ensure that at the end of the extended interim storage the SNF and canister would meet the MGR Disposability Interface Specifications. Focus also is on activities related to retired basin storage facilities.

Investments are needed to identify monitoring needs, design and implement monitoring stations, and for new systems to detect and measure SNF changes during the extended storage period. Investments are needed to ensure that SNF data may be qualified and verified prior to shipping to the MGR.

R&D Activities:

- Examination and measurement of all degradation, including pitting, microbiological induced corrosion in water basins, etc.
- Testing of Al-based SNF in experimental instrumented dry-storage test devices.
- Detecting moisture remaining within a complex geometry fuel element.
- Drying physically entrained water in SNF.
- Programming computer codes for optimal loading of dual-purpose canisters.
- Mechanically drying carbon/graphite SNF.
- Removing epoxy materials before placement into dry storage.
- Inserting metal corrosion coupons into dry storage systems.
- Examining basin stored SNF for degradation e.g. pitting, micro-biologically induced corrosion etc.
- Detecting and mitigating microbiologically induced corrosion in SNF dry storage containers.
- Detecting interactions between SNF and storage containers.
- Inserting Representative Treated SNF Form Coupons in dry storage systems.
- Defining and acquiring appropriate instruments and sensors for SNF performance monitoring.

- Developing instrumented test canister system for monitoring of long term performance.

Experiments have been designed to simulate long-term, environment-specific performance of spent fuel and high-level waste glasses. Test methods and test protocols are being processed through American Society for Testing and Materials (ASTM) committees to facilitate establishment of consensus standards for SNF and high-level waste glass. A second focus is on NDA/NDE systems and techniques for fissile and radioisotopes, for detecting water (bound or free) in SNF canisters, and for ensuring continuing fuel-handling capabilities. Burn-up meters and uranium isotopic analytical systems are being developed for aluminum SNF.

Accomplishments:

- A detailed, preliminary design of a standardized canister (18” or 24” Dai.) has been completed. The canister is designed for 50 psig and drop heights up to 10 meters for stored SNF.
- Corrosion data in dry (and humid) storage environments have been developed for aluminum SNF.
- The storage criteria (acceptance criteria) have been developed for aluminum SNF defining the window of temperature, humidity and drying condition.
- Drying systems have been demonstrated and used at three major sites managing and storing SNF.
- Systems for detecting water in canned SNF have been demonstrated.
- Drying tests have been performed on a variety of simulated SNF including Al based fuels.
- Instrumentation required for monitoring SNF performance has been developed and incorporated into test packages.
- Thermal models for aluminum SNF in interim dry storage packages have been developed.
- Criticality models for aluminum SNF in interim dry storage have been developed.
- Performed placement of stainless steel coupons with basin corrosion products into dry storage conditions for monitoring potential for continued corrosion.
- An experimental instrumented test canister has been developed and long-term dry storage of aluminum SNF in the instrumented test canister is under way.
- The performance of aluminum SNF in dry storage (both corroded and non-corroded) SNF are being monitored in the instrumented test canister.

- An NDE magnetic resonance imaging system for measuring water content is being evaluated.

Directed Science

Budget: FY99-$2.1M, FY00-$2.4M, FY01-$1.8M

The Department funds research that advances science to solve environmental problems associated with safely and efficiently managing spent nuclear fuel from both domestic and foreign reactors. Six subcategories of needs were identified in the area of spent nuclear fuel:

- Stabilization of spent nuclear fuel, including mechanisms of pyrophoricity and combustion parameters for various fuel types.

- Characterization/nondestructive examination (moisture content, radioisotope inventory, physical condition, criticality, and synergistic effects) of spent nuclear fuel.

- Characterization corrosion, degradation, and radionuclide release mechanisms, kinetics, and rates for the representative fuel matrices; mechanisms which may lead to accelerated degradation of containers; dissolution characteristics of the matrices; and the effects of microbes on fuel packages; long-term storage and deterioration of fuel/canisters of spent nuclear fuel.

- Characterization of water clarity of basins.

- Development of alternative spent nuclear fuel processes; waste forms; alternative disposal process; mixed oxide fuels.

- Development of methods to remove moisture without damage to the fuel elements.

The spent fuel directed research portfolio is concentrated in the scientific areas of analytical chemistry and instrumentation, engineering science, geochemistry, separations chemistry, materials dynamics and computational simulation.

- *Analytical Chemistry and Instrumentation.* Development of detectors for direct imaging of spent nuclear fuels and fissile materials, applying high-resolution gamma-ray imaging technologies to environmental remediation of radioactive hazards, investigating fabrication of field-usable detectors, and demonstrating the performance of such a system using a small configuration of detectors.

- *Engineering Science.* Developing techniques to model fluid flow in spent nuclear fuel canisters. The primary goals are to a) develop a method to visualize flow in the presence of a reacting surface, b) use the Matched-Index-of-Refraction facility at the INEEL in conjunction with laser doppler velocimetry to measure flow field velocities within a spent fuel canister, and c) develop a computer model of the flow field and use the experimental results to validate the code.

- *Geochemistry.* Long-term assessment of radionuclide immobilization in the phases formed by corrosion of spent nuclear fuel and immobilization of radionuclides in the alteration phases of spent fuel. This requires a careful analysis of direct disposal of spent nuclear fuel or of mixed oxide fuel (fabricated for the disposal of excess weapons plutonium).

- *Separations Chemistry*. Specific research is being conducted in the area of catalyst chemistry and waste treatment. This task will study the radiolytic reactions, "drying" processes, and corrosion behavior of actual SNF materials. A model will be developed and tested against actual fuel rod behavior to insure validity and applicability to the problems associated with developing dry storage strategies for DOE-owned SNF.

- *Materials Dynamics.* Characterization, predictions, and mitigation of changes in the microstructure and properties of materials over very long periods of time. Three particular topics with the general area of dynamic behavior of materials are of particular concern:

  (a) *Transport in Solid and Liquid Media.* There is a need to determine the effective macroscopic transport properties of an inhomogeneous media from its microstructural morphology. The research includes (1) development of methods to quantitatively characterize complex microstructures, and (2) development of analytical and computational models to calculate effective transport properties from the microstructure characterization and the equations of motion for the phenomena of interest. The transport properties of particular interest are thermal and electrical conductivity, fluid permeability, and diffusion of molecular species. Both static and dynamic (non-equilibrium) microstructures are considered. Phenomena to which this work may be applied include leaching from waste forms, molecular diffusion through storage containers, trapping of contaminants at surfaces in porous media, vitrification by resistance heating, and production of thermal gradients by chemical and nuclear reactions in stored waste.

  (b) *Corrosion and Aging.* There is a lack of fundamental information on the role of microbiological activity in spent nuclear fuel storage basins and on spent nuclear fuel surfaces. Focus will be on examining the attachment of microorganisms on aluminum alloys, stainless steels, and zircalloy and to develop an understanding of the deterioration of the passivation layer on the substrate, which leads to localized corrosion beneath the biofilm. A particular focus will be to examine the biocorrosion of weldments that are thought to be localized areas of chemical inhomogeneity compared to wrought parent materials.

  (c) *Coatings for Environmental Applications.* Despite the successful use of coatings in some engineering applications there is very limited scientific understanding of either the coating process or the resulting materials properties. Aspects of spray coating processes will be examined in order to determine the relationship between particle size, velocity, and temperature as well as the coating microstructure and mechanical properties. The role of process variations and surface preparation methods on residual stress and bonding will be examined using finite element numerical simulations and experimental measurements to better understand bonding between coatings and substrates, particularly oxidized or corroded materials.

- *Computational Simulation of Mechanical and Chemical Systems:* Delivery of computational modeling capability and results for chemical and physical processes that occur in the wide range of systems of importance to DOE EM.

  (a) Computational Simulation. Computations to support the understanding of fracture propagation in materials and the interfacial properties of coatings and their substrates that relate to coating performance.

Budget Summary Table

(Dollars in thousands)

Program Activity	FY 1999 Appropriation	FY 2000 Request	FY 2001 DOE Request
Data Acquisition and Validation	1,080	1,600	2,220
Treatment or Conditioning	44,391	28,100	30,484
Packaging for Dry Storage	900	1,690	1,780
Directed Science	2,101	2,350	1,835
Total	**48,472**	**33,740**	**36,319**