DISPOSITION STRATEGY FOR USED FUEL RESEARCH SAMPLE WASTE

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel Disposition Campaign
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SUMMARY

This report presents a national strategy for managing the research samples and the subsequent waste materials arising from supporting research and development needs in commercial nuclear fuel. Specific activities within the Used Fuel Disposition (UFD) program have identified the information needs required to close known experimental data gaps. An integrated waste management strategy consistent with the sample management strategy would provide the greatest programmatic flexibility. Integrated strategies for both sample management and waste management will provide a balance between the cost of duplicating existing capability and the need to demonstrate repeatability and provide independent verification of results.

The UFD campaign has established a clear set of data needs and their priorities with respect to moving forward with establishing a regulatory basis for the extended storage and subsequent transportation of used nuclear fuel (UNF). The identified data gaps demonstrate the need to obtain additional data to validate/develop performance models necessary for the successful execution of the UFD mission. Several national laboratories possess sets of unique capabilities to develop and enhance the data required to fill the identified gaps. The national laboratories routinely handle radiological materials largely related to our nation's defense programs with existing processes and procedures to safely perform testing and the operations to manage the radiological hazards. The sample materials required to satisfy the UFD data gaps will in most cases include physical samples of used nuclear fuel and/or associated structural materials within the fuel assemblies. This report addresses only the fuel sample materials.

This report outlines a concept for an integrated sample and waste management plan with a focused discussion on incorporating a waste disposition strategy to support testing with samples of commercial used fuel. An integrated strategy is recommended to resolve the identified data gaps in a cost-effective and timely manner. The need for this strategy is immediate. The overall sample and test strategy of the UFD campaign will need to be a coordinated effort with careful selection of tests, participants, and sample materials. Recommendations for near-term activities to move forward with the mission of providing the data required to advance the UDF campaign are listed below.

Recommendation 1 Investigate the feasibility of successfully implementing the hub-and-spoke model
The hub-and-spoke model is the key to "right-sizing" samples and therefore minimizing waste. It is recommended that the roles and responsibilities for the coordinating and performing laboratories, utility research partners, U.S. Department of Energy field offices and the UFD campaign should be clarified. This includes identifying potential candidates for each role as well as the key stakeholders for each potential site that would receive the research samples.

Recommendation 2 Develop a detailed UFD Integrated Test Matrix
The key component of an integrated program for managing used fuel research samples and waste is establishing and validating the Integrated Test Matrix (ITM). It is recommended that a detailed UFD ITM be developed including establishing "right-sizing" by identifying specific tests to address each need, clarifying the range of fuel conditions (enrichment, burnup, age, etc.) required for each test and data need, and cross referencing specific laboratories and capabilities to the data needs

Recommendation 3 Evaluate the components of a detailed transportation plan for research samples
Since development of a comprehensive transportation plan is a long lead time activity, it is recommended that the UFD campaign move forward to evaluate commercially available transportation packages for use, define the infrastructure requirements to move fuel, including any shipper/receiver agreements, as well as identifying all the regulations and requirements affecting any proposed transportation route. The near-term goal is to establish the activities and schedule for a detailed transportation plan.

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TABLES

ACRONYMS

BRC	Blue Ribbon Commission on America's Nuclear Future
BWR	boiling water reactor
DOE	U.S. Department of Energy
DSA	documented safety analysis
GTCC	greater than Class C
HLW	high-level waste
ITM	Integrated Test Matrix
LLW	Low Level Waste
NAC	Nuclear Assurance Corporation
NRC	Nuclear Regulatory Commission
PNNL	Pacific Northwest National Laboratory
PWR	pressurized water reactor
R&D	research and development
RD&D	research, development, and demonstration
RPL	Radiochemical Processing Laboratory (at PNNL)
TRU	transuranic
UFD	Used Fuel Disposition
UNF	used nuclear fuel
WAC	waste acceptance criteria
WIPP	Waste Isolation Pilot Plant

DISPOSITION STRATEGY FOR USED FUEL RESEARCH SAMPLES

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) Used Fuel Disposition (UFD) Program has identified a number of activities to support development and implementation of a national strategy for long-term management of used nuclear fuel (UNF). The *Nuclear Energy Research and Development Roadmap* (DOE-NE 2010) presented a plan using a predictive approach that first develops performance models which are then confirmed through an engineering-scale demonstration. The science-based predictive models rely heavily on single effects and small-scale testing combined with advanced modeling and simulation. Using this approach, a systematic review and prioritization of the data needs (gaps) related to U.S. Department of Energy Office of Nuclear Energy (DOE-NE) programs focusing on the commercial nuclear waste management including potential reprocessing or geologic disposal was performed (DOE 2012).

The identified data gaps demonstrate the need to obtain additional data from used commercial fuel to validate and develop performance models necessary for the successful execution of the UFD mission. Several national laboratories possess sets of unique capabilities to develop and enhance the data required to fill the identified gaps. The national laboratories routinely handle radiological materials largely related to our nation's defense programs with existing processes and procedures to safely perform testing and the operations to manage the radiological hazards. The sample materials required to satisfy the UFD data gaps will in most cases include physical samples of used nuclear fuel and/or associated structural materials within the fuel assemblies. This report addresses only the approach for acquiring, testing and disposing of fuel rod sample materials needed for research, development and demonstration (RD&D) purposes.

Managing research samples of commercial used nuclear fuel at a national laboratory is no different than other radiological materials, i.e., the same basic requirements, procedures, and protocols are maintained. The difference is that there is no clear disposition path for any sample material that is not consumed in the experiment itself. Currently, the only licensed repository in the United States is the Waste Isolation Pilot Plant, whose waste acceptance criteria for transuranic (TRU) waste is limited to defense-related waste, and excludes commercial nuclear fuel.

The purpose of this report is to further review the anticipated excess used fuel samples and associated waste materials and to identify disposition pathway options and alternatives. This report also provides recommendations for the management of spent fuel sample materials that will be used to perform RD&D activities.

1.1 Background

Used nuclear fuel continues to be produced by the nation's 104 operating commercial power reactors. As reactor pools reach their capacity, fuel is being moved into dry cask storage systems and stored at the reactor sites. As a result of delays and, most recently, the decision that Yucca Mountain is not a workable option, the duration of the dry storage period and quantity of fuel that must ultimately be accommodated are steadily increasing.

Today, there are over 1,421 casks in service and it is estimated that nearly 5,000 casks will be in service if a repository opens in 20 years (2031). If it takes several decades before a repository is operational, the number of casks in service will increase significantly. (Nichols 2012).

Figure 1.1 (Carter and Luptak 2010) provides a picture of the growth of used fuel inventories through 2100 under four different potential future nuclear growth scenarios, assuming no other means of disposition. The lowest line in Figure 1.1 corresponds to the 'no new nuclear build' scenario. The other three scenarios show the quantity of UNF that must be stored under a "maintain current nuclear capacity (~100 GWe/yr) and growth scenarios with nuclear capacities of 200 and 400 GWe/yr." Figure 1.1 illustrates that the quantity of fuel in dry storage is likely to be 500,000 to over 1 million assemblies, depending on the nuclear growth scenario.

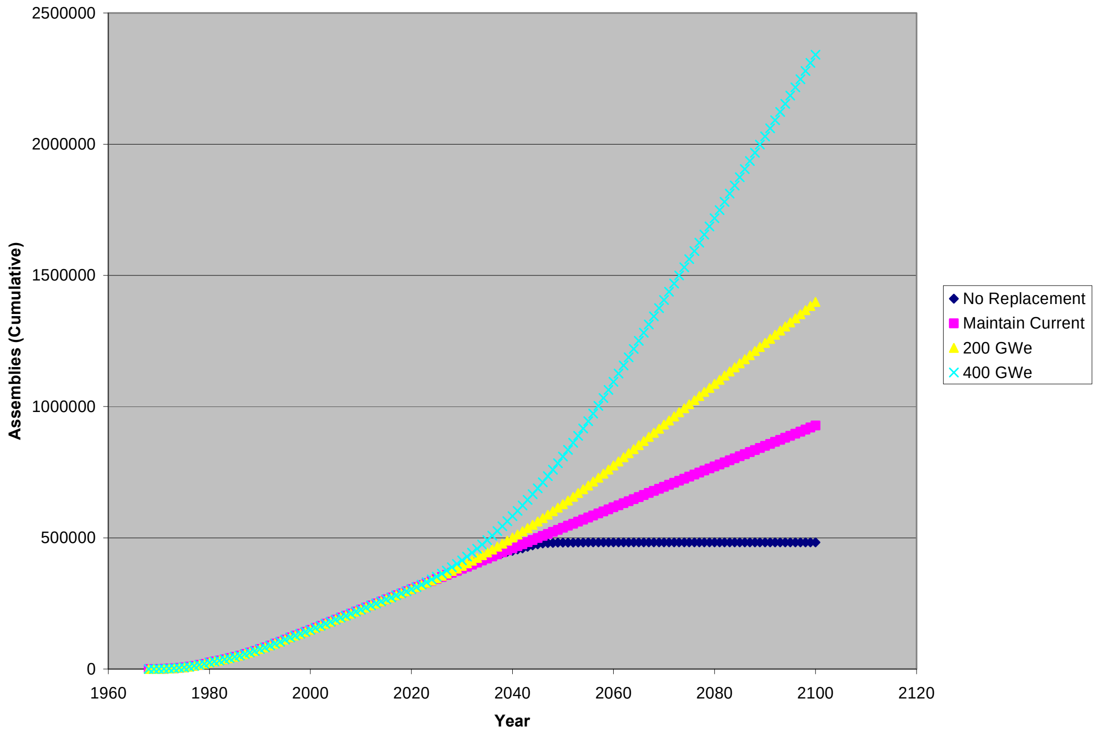


Figure 1.1. Cumulative UNF Assemblies Discharged for no Nuclear Power Plant Replacement, Maintain Current Capacity, and for 200 GWe/year and 400 GWe/year growth scenarios

Until a means of final disposition or another alternative to onsite dry storage becomes available, UNF in dry storage will continue to accumulate. As more of the U.S. UNF inventory is placed into on-site dry storage, the locations, types of fuel, types of dry storage systems, and range of UNF conditions will also become more diverse.

The Blue Ribbon Commission on America's Nuclear Future (BRC) was chartered to recommend a new strategy for managing the back end of the nuclear fuel cycle. The final BRC report included a recommendation to exercise prompt efforts to establish a geological repository and a consolidated storage facility. The BRC concluded that a

> "Deep geologic disposal capacity is an essential component of a comprehensive nuclear waste management system for the simple reason that very long-term isolation from the environment is the *only* responsible way to manage nuclear materials with a low probability of re-use, including defense and commercial reprocessing wastes and many forms of spent fuel currently in government hands. The conclusion that disposal is needed and that deep geologic disposal is the scientifically preferred approach has been reached by every expert panel that has looked at the issue and by every other country that is pursuing a nuclear waste management program" (BRC, 2012).

The BRC also concluded that one or more consolidated storage facilities should be established, independent of the schedule for opening a repository.

If implemented, the BRC recommendations will require timely resolution of the existing gaps in our knowledge base for long-term dry storage and transportation. The necessity to use research quantities of used commercial nuclear fuel to address these data gaps is essential for identifying definitive disposition paths for waste and excess sample materials generated as a by-product of these measurements and tests.

The Used Fuel Disposition (UFD) program has identified the RD&D activities required to close known experimental data gaps. An integrated waste management strategy consistent with the sample management strategy would provide the greatest programmatic flexibility. Integrated strategies for both sample management and waste management will provide a balance between the cost of duplicating existing capability and the need to demonstrate repeatability and provide independent verification of results.

Utilizing the cumulative capabilities of the DOE laboratories is necessary to provide backup against single failure drivers in this science-based engineering-driven approach. An integrated process to manage both used fuel samples and waste is recommended to resolve the identified data gaps in a cost-effective and timely manner. This process would include the cradle-to-grave plan for the management of the commercial fuel that DOE will need to possess in order to perform the RD&D needed for closing the fuel cycle. The need for this plan is immediate. The overall sample and test strategy of the UFD campaign will need to be a coordinated effort with careful selection of tests, participants, and sample materials. In addition to the technical veracity of the data to be developed, cost and schedule will also be important factors to consider. Flexibility and the capability to perform independent measurements in order to reduce the data uncertainties and to identify and investigate discrepancies and outliers are a necessary part of the integrated strategy.

1.2 Document Overview

Section 2 summarizes the overall used fuel RD&D needs and the various waste management disposal considerations to be addressed as a part of the overall UNF strategy. This report presents a national strategy for managing the research samples and the subsequent waste materials arising from resolving these data gaps. Section 3 discusses the potential pathway options and recommendations. The overall challenges to establishing a coordinated national program for managing both commercial fuel sample materials and the subsequent waste materials from RD&D activities associated with the characterization of these samples are discussed in Section 4. In Section 5 recommendations are made to identify the next steps in establishing an infrastructure for a coordinated disposal strategy. Appendix A includes a brief discussion and the excerpted executive summary from *Gap Analysis to Support Extended Storage of Used Nuclear Fuel* (the Gap Analysis Report, DOE 2012a).

2.0 Potential Waste Management Considerations

Many state and local organizations have a stake in the various waste management disposal considerations that need to be addressed in the strategy for managing the research samples that will be necessary to perform required RD&D activities. This report identifies the waste management considerations for the UFD campaign. The waste issue is reviewed from a national programmatic perspective, which will be needed to effectively manage waste from the RD&D activities to close the experimental data gaps.

The waste management strategy proposed here focuses on three objectives:

- minimize or eliminate waste generated from research and operations, by right-sizing samples
- minimize or eliminate future waste liabilities resulting from research and operations by consolidating the accumulation of waste in a single location
- enable research through safe, compliant, and efficient disposition of all generated waste.

2.1 RD&D-Related Needs and Coordination

DOE-NE is supporting development of the technical basis for certification of very long-term storage of used fuel and subsequent transportation, including the transportation of high burnup fuel. This includes developing a plan to support experimental data gathering to address gaps in the existing database and conducting experiments to gather needed data. These data gaps are referenced in the UFD document *Gap Analysis to Support Extended Storage of Used Nuclear Fuel* (DOE 2012a) and subsequently prioritized in *Used Nuclear Fuel Storage and Transportation Data Gap Prioritization* (DOE 2012b) Programmatic guidance is being developed to address in more detail the execution plan for closing these gaps. It is anticipated that filling these data needs could be most efficiently accomplished by integrating the DOE national laboratories using a hub-and-spoke model as illustrated in Figure 2.1. A single laboratory or facility would act as the coordinating laboratory ("hub" at the center of Fig. 2.1). The principal role of the coordinating laboratory would be to interface with the utilities for the initial receipt of fuel rods and the preparation of RD&D samples for use at a performing laboratory ("spokes", green circles in Fig. 2.1).

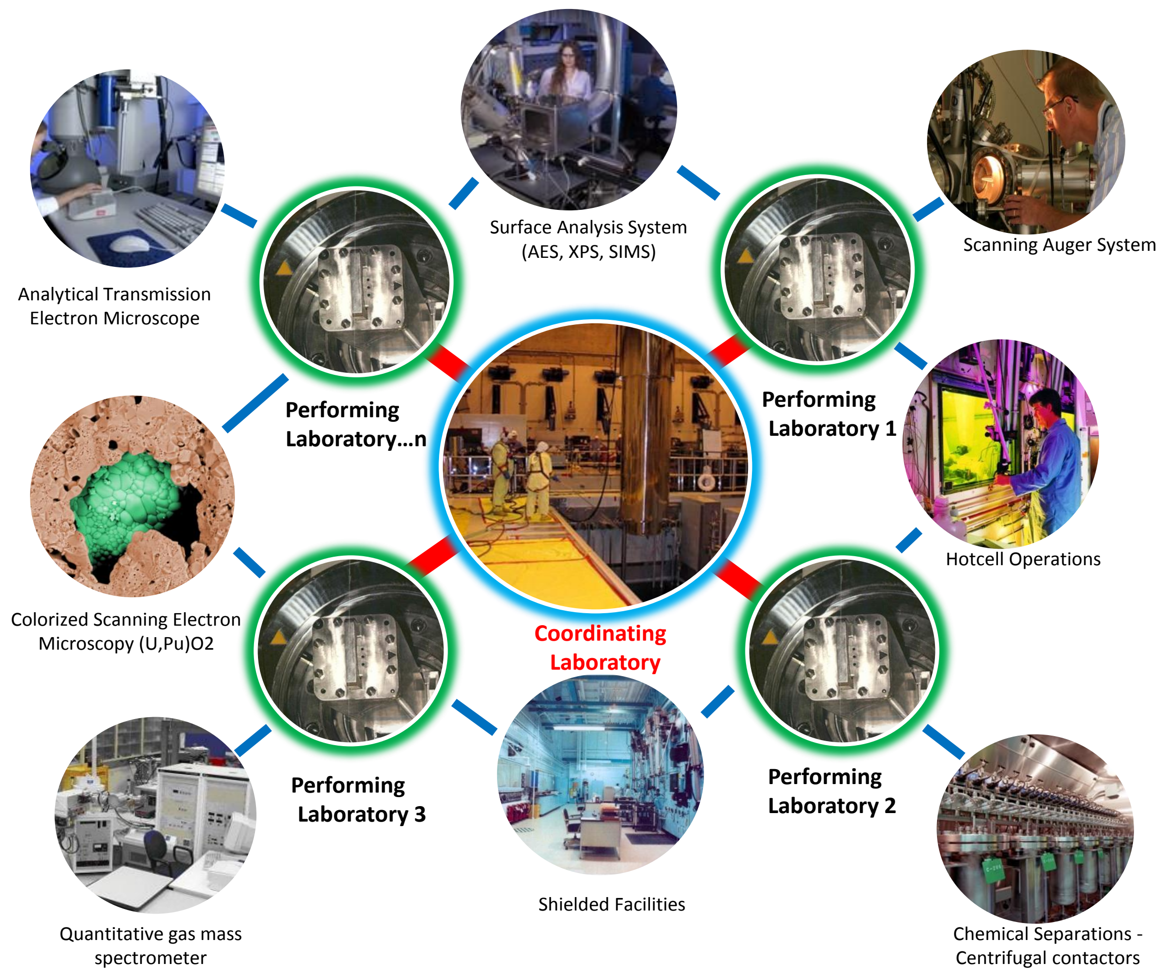
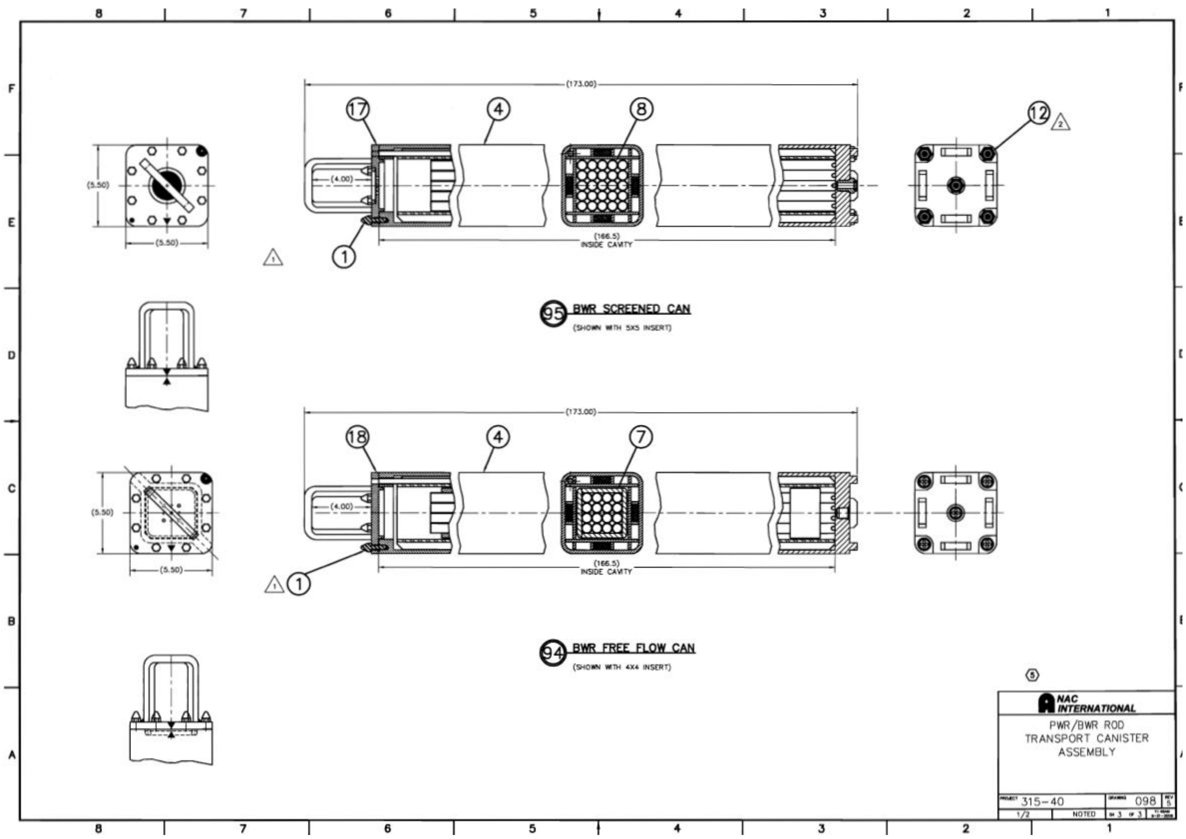


Figure 2.1. Illustration of Hub-and-Spoke Model Supporting Integrated Used Fuel Research, Development and Demonstration and Waste Disposition

Any number of performing laboratories can be accommodated in this model including a dual role for the coordinating laboratory (i.e., the coordinating laboratory may also be a performing laboratory). The design of modern pressurized water reactor (PWR) and boiling water reactor (BWR) fuel assemblies permit the removal and transport of individual fuel pins via commercially available casks and basket structures such as those provided by the Nuclear Assurance Corporation (NAC) (see Figure 2.2). The receipt and management of fuel pins greatly reduces the amount of commercial fuel for which DOE and the UFD campaign would need to take responsibility. The performing laboratories at the end of each of the spokes would enable the program to take the maximum advantage of existing RD&D across the DOE complex. One of the most significant advantages of this coordination is that it enables the development of right-sized samples and minimizes the accumulation of excess sample material and waste at the performing laboratories. Furthermore, the distribution of materials is targeted for specific measurements consistent with each of the laboratories capabilities.



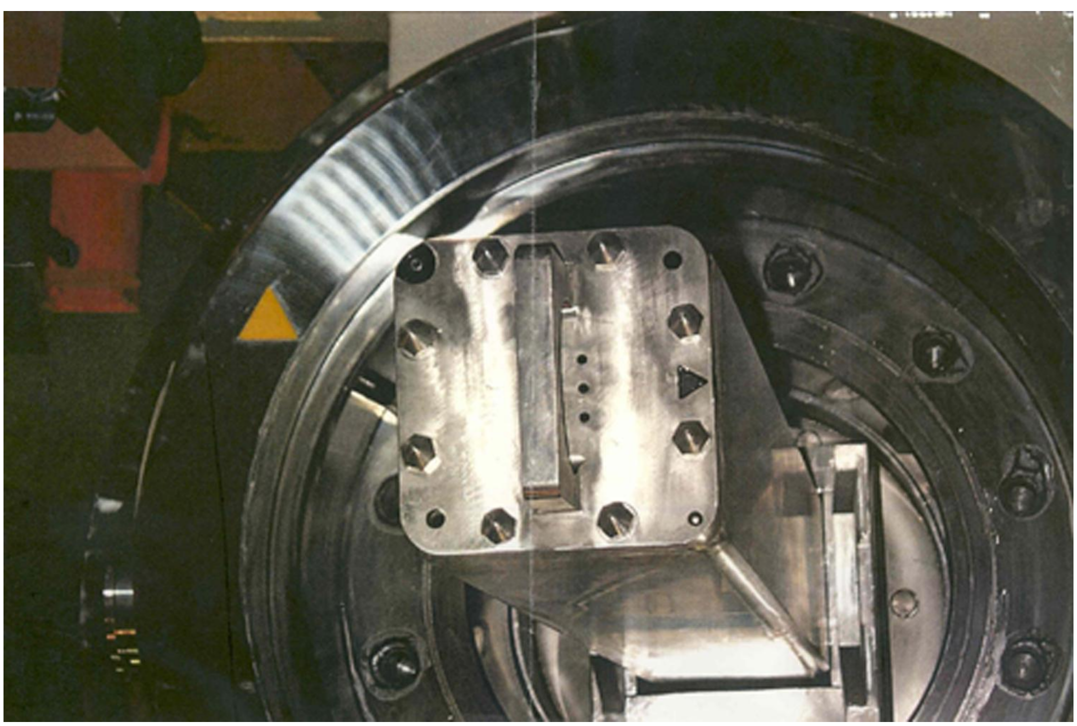


Figure 2.2 Nuclear Assurance Corporation PWR/BWR Transport Canister

2.2 Projected Waste Generation from Used Fuel RD&D

Waste planning, projection of waste generation, and associated costs should be incorporated into any waste management strategy. RD&D work required to meet the used fuel data needs identified in the Gap Analysis report (DOE 2012a) generates a diverse population of wastes including hazardous, low-level radioactive waste (LLW), TRU, and radioactive mixed wastes. In order to effectively and efficiently manage these wastes, each national laboratory should have developed a laboratory waste management strategy. In addition, it is not unusual for DOE programs that are heavily dependent on the measurement and evaluation of irradiated materials to generate programmatic waste management plans. Table 2.1 identifies the common waste forms that are expected to be generated in the study of used fuel. Typically the identified waste stream can be correlated with a defined waste type and waste acceptance criteria (WAC).

The primary concern is the generation of radioactive waste that does not fit into existing waste management plans because it does not meet the WAC for any of the present disposal sites. Since all major waste types, TRU waste and LLW have specific wastes that require some treatment prior to disposal, it is reasonable to assume that some treatment of the RD&D wastes will be necessary (e.g. grouting liquid waste forms, compaction, etc.). Even after treatment, there is presently no approved final disposal site for segregated high-level waste (HLW) from commercial nuclear fuel. Also the WAC for the Waste Isolation Pilot Plant are restricted to TRU produced as a result of defense-related activities. There is no established disposition path for TRU waste from commercial nuclear fuel. In fact, the designation TRU waste has no legal meaning for commercial wastes, and again, the actual waste definition defaults to greater-than-Class C (GTCC) waste, based on the radioactivity of the material.

Table 2.1 summarizes the composition of wastes anticipated to be generated from the RD&D activities necessary to resolve the technical data needs identified in the Gap Analysis Report (DOE 2012a). Some of the identified data needs will require the fuel material to be dissolved and essentially destroyed as part of the measurement process. There are two cases in which the waste produced is a composition that does not have an established disposal path. The resolution of some data requirements will result in the physical alteration of the fuel form (e.g., bend tests on rod segments with the fuel meat intact, and surface analysis) but will not consume the material. In addition there may be instances in which there is excess sample material simply because of the correlation between the sample preparation and the measurement accuracy that require final sample preparation at the performing laboratory. Given the basic principle that the fuel samples will be right-sized, the volume of excess sample material will be largely minimized. However, even considering waste minimization there remain two cases which will result in the undesirable potential to collect orphan waste at the performing laboratories.

Considering the economics of managing these orphan wastes from a qualitative perspective, the situation is analogous to the problem of the orphan sites in the overall used fuel management strategy for the United States. Having multiple sites where material is stored inherently increases the programmatic risk and cost of maintaining these sites in compliance with the requirements. In the case of orphan waste, the risk is that operational errors in the packaging or handling of the wastes may occur increases with time. Tracking the inventory in each location and the long-term responsibility for providing funding up to and including the final disposition of the waste become a mortgage without a limit. Although there are unknowns related to the final disposition of HLW, the requirements for transporting these materials are well established. The programmatic risk and long-term mortgage can be potentially minimized by consolidating these orphan wastes into one location. Based on the logistics of implementing the integrated sample management program it would be most efficient if the central location (for treatment and packaging for disposal) were the coordinating laboratory since they will have the bulk of the material to start with. Establishing the conditions under which this practice would be acceptable would require establishing very specific requirements as the form and quantity (both mass and volume) of the materials that could be returned to the coordinating laboratory in addition to any requirements that are necessary for the performing laboratory to produce and handle these materials. The quantity of material that would in practice be returned to the coordinating laboratory will be heavily influenced by the handling of the used fuel sample and sample excess at the performing laboratory. Therefore, the next step in developing an integrated waste management strategy is to establish a protocol for the management/treatment of these wastes at the performing laboratory.

Table 2.1. Anticipated Wastes from Spent Fuel Research[a]

Anticipated Waste Composition[b]	Potential Source	Assumptions	Potential Disposition Pathway
Hulls/Cladding (Zr/SS) hardware from processing oxide fuels	Residuals following fuel dissolution washed to LLW levels using HF and HNO_3	Not TRU waste	LLW-SLB LLW-GTCC
Fuel fragments	Residuals following mechanical testing or sample preparation	If segregated TRU waste from commercial nuclear fuel, potentially HLW	
Undissolved solids	Sludge remaining after dissolution potentially containing noble metals and TRU	Assumed to be comingled with laboratory waste and not easily separated	Disposition with laboratory TRU waste
Dissolved TRU stream	Product of fuel dissolution and chemical separations	Assume laboratory operations and/or MC&A results in comingling with existing "like" laboratory waste[c]	Disposition with laboratory TRU waste
Liquid waste (aqueous and organics)	Spent solvents, solvent wash solutions, laboratory returns, and other miscellaneous liquids	Assumed to be comingled with other laboratory waste and not easily separated	Stabilize and dispose as LLW
Miscellaneous solid debris	Spent equipment, PPE, laboratory and operations solid waste (pipettes, wipes, gas filters, etc.), after decontamination.	Normal laboratory waste	LLW-SLB
Excess fuel sample material	Inefficient right-sizing; final sample preparation at performing laboratory	Segregated TRU waste from commercial nuclear fuel, potentially HLW	

[a]Red cells indicate no existing waste acceptance criteria
[b]Gombert II, D. 2007. *Draft Global Nuclear Energy Partnership — Materials Disposition and Waste Form Status Report*, GNEP-WAST-AI-TR-2007-00013.
[c]Assumes that no long-term storage of unstabilized or liquid wastes will be allowed.
GTCC = greater than Class C
HLW = high-level waste
LLW = low-level waste
MC&A = material control and accounting
PPE = personal protective equipment
SLB = shallow land burial
SS = stainless steel
TRU =transuranic

3.0 Strategy for Handling UFD Sample Materials at Performing Laboratories

This section outlines a draft strategy for managing UFD sample material once it is received at a performing laboratory. The objective is to establish *a priori* the guidelines and requirements for managing the waste materials that may be generated at the performing laboratory as described in Table 2.1. The steps of this strategy follow.

1. Upon receipt at the performing laboratory, sample materials shall be confirmed to be consistent with the requirements as specified in the ITM.
2. The laboratory should not accept sample materials that cannot be verified to be consistent with the agreement between the laboratory and the UFD program.
3. Upon acceptance, the performing laboratory becomes responsible for safely and securely storing the sample materials.
4. The performing laboratory is responsible to incorporate the guiding principle of waste minimization in their execution of the RD&D.
5. Waste materials produced shall be "graded" by type as described in Table 2.1 as well as potential for use by alternate programs. The grading of waste material should evaluate
    a. Does the waste meet established WAC for LLW?
    b. If TRU or HLW, has the sample been mechanically altered?
    c. Does the sample contain segregated TRU materials?
    d. Would the sample require additional processing to segregate the TRU materials?
    e. Is there additional risk of exposure or the generation of an additional volume or form of waste that would result from further processing?
    f. Is there a potential the sample material may be suitable for additional testing such as radiochemistry and waste form analysis for another program (not UFD)? The terms for the transfer of responsibility for materials retained for other than UFD programmatic purposes should be defined and agreed upon before transfer of the material.
6. An approved method for interim storage is available. Interim storage could be provided with containers that are approved by the facility for this use or are certified Type B packages (NNSA 2012). For example, at Pacific Northwest National Laboratory (PNNL), the Documented Safety Analysis (DSA) for the Radiochemical Processing Laboratory (RPL) permits the exclusion of material stored in qualified containers[a] (RPL-SA-R6) from the radiological material inventory for RPL. The use of certified packages negates the need for additional analysis/expense to qualify the container. However, the cost of the certified package (even when leasing) may far exceed the cost of the analysis required to qualify a container for this purpose. Under circumstances like this, an economic evaluation should be performed to justify the approach taken.

Efficiently managing the waste from RD&D activities should include a grading system to segregate waste by disposition path. Specific criteria should be developed for this process. The following is an example of criteria for a grading system:

Grade 1 - all material has been converted to disposable form. Destructively analyzed materials, particularly those subjected to radiochemistry processes, will produce minimal wastes that are consistent

[a] Qualified containers are containers for storage of radioactive materials that can be exempt from the RPL radiological material inventory as material at risk (MAR) in relation to the DSA accidents. Qualified containers are assumed to remain intact during the fires, explosions, spills and seismic events analyzed in the DSA (per RPL-SA-R6).

with and can be incorporated into the existing liquid waste stream. Transuranic waste and transuranic mixed waste are shipped to the Hanford Central Waste Complex for certification and eventual disposal at the WIPP in Carlsbad, New Mexico. The DOE Office of Environmental Restoration completes certification of the waste and transportation to WIPP.

Grade 2 – material not destroyed has high attractiveness for identified study, and is therefore not designated as waste. Store retained material on-site in a qualified container. A good example of Grade 2 material would be remaining material from a split sample which is held for testing in the event measurement discrepancies/errors are identified in the primary sample material. Additional uses of this material could be as known samples for qualifying/training laboratory technicians. Responsibility for final disposition must be transferred to an appropriate entity for any Grade 2 material retained by the performing laboratory for use outside the UFD program. Grade 2 material remains the responsibility of the UFD campaign will be returned to the coordinating laboratory for consolidated storage upon completion of the scheduled RD&D activities.

Grade 3 – material not destroyed has limited potential for use at the laboratory and should have limited retention before being designated as waste. The intent would be to store this material in the building within a qualified container, perhaps similar to waste container currently in use. These quantities will likely be small in comparison with the material already generated at the laboratory. Both Grade 2 and/or Grade 3 material would require the appropriate permitting and certification for qualification of those interim storage containers. Grade 3 materials may be retained at the performing laboratory for a limited period with the requirement to return material to the coordinating laboratory for consolidated storage at the end of that period.

Grade 4 – waste directly generated during receipt, storage and utilization of UFD sample materials. Grade 4 material is not TRU, contaminated waste, low-level radioactive and/or radioactive mixed waste. Disposal of radioactive and mixed low level waste should be routine for each performing laboratory. For example, the Hanford Site 200 West Area Low-Level Waste Burial Grounds, and the Energy Solutions waste landfill near Clive, Utah are used for disposal of government wastes. Non-government radioactive waste generated under the current PNNL Use Permit is disposed at the US Ecology landfill located on the Hanford Site.

Figure 3.1 is a flow chart illustrating how these criteria could be implemented as a process for managing used fuel samples and waste at a performing laboratory. In this example Grades 1 and 4 have definitive disposal paths. The performing laboratory would be responsible for providing documentation of a final disposition path for any Grade 2 material. Grade 3 material could be stored on-site temporarily awaiting any required treatment or packaging for return to the coordinating laboratory. The coordinating laboratory would serve as the consolidated storage facility for the UNF materials awaiting final disposition.

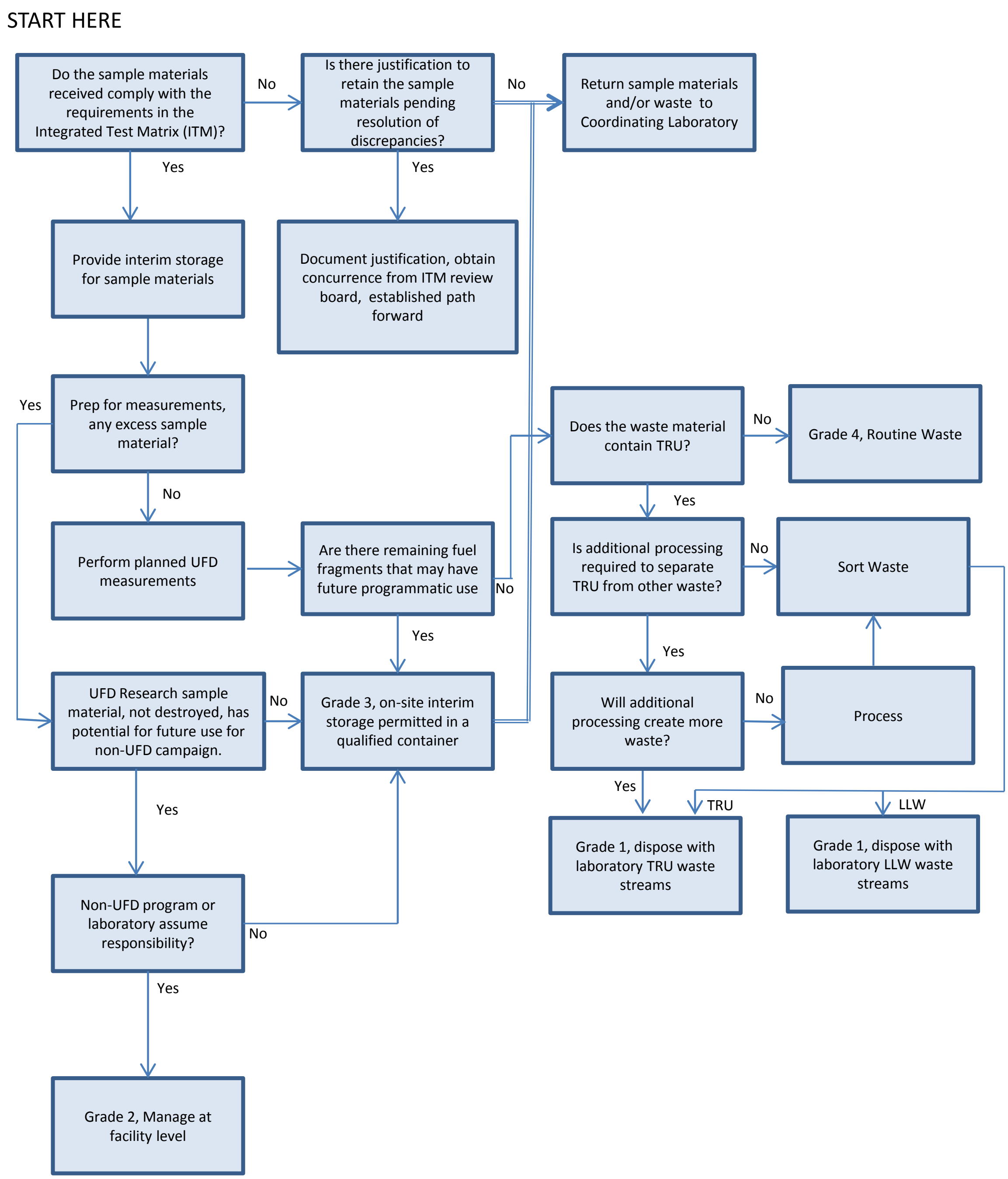


Figure 3.1. Flow Chart of Sample Process for Managing Used Fuel Samples and Waste at Performing Laboratories

4.0 Challenges to Establish a Coordinated National Program for Management of Waste from Commercial Fuel Samples for Research

The lynch pin of an integrated program for managing used fuel research samples and waste is establishing and validating the ITM. The principle challenge is the need to establish and maintain effective relationships amongst the many stakeholders, including the national laboratories, utilities, and the regulatory authorities at the state and federal level. The details of these challenges will vary somewhat from site to site, depending on the history of the laboratory and DOE with the local community. The relationship between DOE and the stakeholder utilities that are a necessary part of strategy will also be important to success. In most cases, the state governments have also established a position relative to the targets, goals, and policies related to the potential inventory of HLW they are willing to permit at the DOE laboratory. Clearly articulating the proposal for an integrated test matrix and sample management program that includes the waste streams is essential to success. Developing a communications strategy to involve the stakeholders early in the process, understand their concerns and to incorporate elements into the programmatic structure to accommodate those concerns will be very important to future research with commercial used fuel samples. These communications challenges will require the UFD program to maintain flexibility and provide shareholder value to all concerned entities in their effort to integrate site specific requirements and involve all shareholders.

Figure 5.1 illustrates the primary process steps in developing the proposed concept into a fully integrated strategy. The first step is to establish program goals, identify options for the coordinating laboratory, fully develop an accounting of the performing laboratories and their capabilities and establish baseline requirements for the ITM. In this planning phase, it will be important to identify the federal, state, and local stakeholders. Careful consideration should be given to identifying the applicable regulatory requirements that will apply at all hub-and-spoke laboratories as well as the utility research partners.

Once the roles and responsibilities are detailed and consensus is established, formal contracts and agreements will be established among the participants.

Developing the transportation plan[b] for retrieving fuel from the utilities and providing the timely delivery of samples to the laboratories and retrieving qualified waste material from each of the laboratories will be a separate process step. There are commercially available casks and canisters to facilitate this effort. The program should evaluate the cost/benefit of leasing a cask versus purchasing a cask. The use of a commercial cask and retrieving full-length fuel rods from the utilities should ensure that the operations at the nuclear power plants are within their routine operating envelope. Therefore, no large-scale impacts are anticipated for the utility partners. The transportation plan should verify the use of U.S. Nuclear Regulatory Commission- (NRC-) licensed casks to ensure this is a valid assumption.

Each laboratory will need to assess their operational readiness to receive and perform testing as specified in the ITM. This is likely to include reviews of their safety basis, updating/developing procedures, potentially minor equipment modifications, and staff training.

[b] Appendix B provides an example of the transportation route that includes the national laboratories that could potentially participate as a performing and/or the Coordinating Laboratory. The map also indicates where utilities are located within roughly a 75-mile radius of the laboratory.

The performing laboratories will need to confirm the schedules to conduct the research. In situations where multiple laboratories have a given measurement capability, there can be flexibility to adjust schedules by engaging additional laboratories, as well.

The concepts presented in this report for the disposition of waste and residual used fuel research samples at the performing laboratories must be developed into a UFD waste management plan. The waste management plan should include specific definitions of the different waste compositions and criteria for determining the appropriate disposition path. The waste plan should also establish the detailed requirements for the waste forms that would be accepted at the coordinating laboratory. For example, the coordinating laboratory will only accept dry materials (no liquids), any fuel-based debris should be contained in a container of a specified form and closure requirements, etc.

Any limitations or special restrictions regarding the transportation of the excess material to the coordinating laboratory should be established in the plan as well.

5.0 Conclusions and Recommendations

Moving forward with a definitive plan to address the backend of the fuel cycle has never been more important than it is today. Recent decisions regarding the NRC waste confidence rule, the recommendations from the Blue Ribbon Commission, the aging U.S. nuclear fleet, and the overall public perception of the nuclear waste problem are all high-level indicators that a sustainable nuclear energy program in the United States is at a critical juncture. The UFD campaign has established a clear set of data needs and their priorities with respect to moving forward with establishing a regulatory basis for the extended storage and subsequent transportation of UNF.

This report outlines a concept for an integrated sample management plan and focuses on incorporating an efficient waste disposition strategy to support testing with samples of commercial used fuel. There are three primary recommendations to enable the UFD campaign to move forward with the mission of resolving these data needs and at the same time minimizing the accumulation of special-case waste.

Recommendation 1 Investigate the feasibility of successfully implementing the hub-and-spoke model
The hub-and-spoke model is the key to “right-sizing” samples and therefore minimizing waste. It is recommended that the roles and responsibilities for the coordinating and performing laboratories, utility research partners, U.S. Department of Energy field offices and the UFD campaign should be clarified. This includes identifying potential candidates for each role as well as the key stakeholders for each potential site that would receive the research samples.

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The key component of an integrated program for managing used fuel research samples and waste is establishing and validating the Integrated Test Matrix (ITM). It is recommended that a detailed UFD ITM be developed including establishing “right-sizing” by identifying specific tests to address each need, clarifying the range of fuel conditions (enrichment, burnup, age, etc.) required for each test and data need, and cross referencing specific laboratories and capabilities to the data needs

Recommendation 3 Evaluate the components of a detailed transportation plan for research samples
Since development of a comprehensive transportation plan is a long lead time activity, it is recommended that the UFD campaign move forward to evaluate commercially available transportation packages for use, define the infrastructure requirements to move fuel, including any shipper/receiver agreements, as well as identifying all the regulations and requirements affecting any proposed transportation route. The near-term goal is to establish the activities and schedule for a detailed transportation plan.

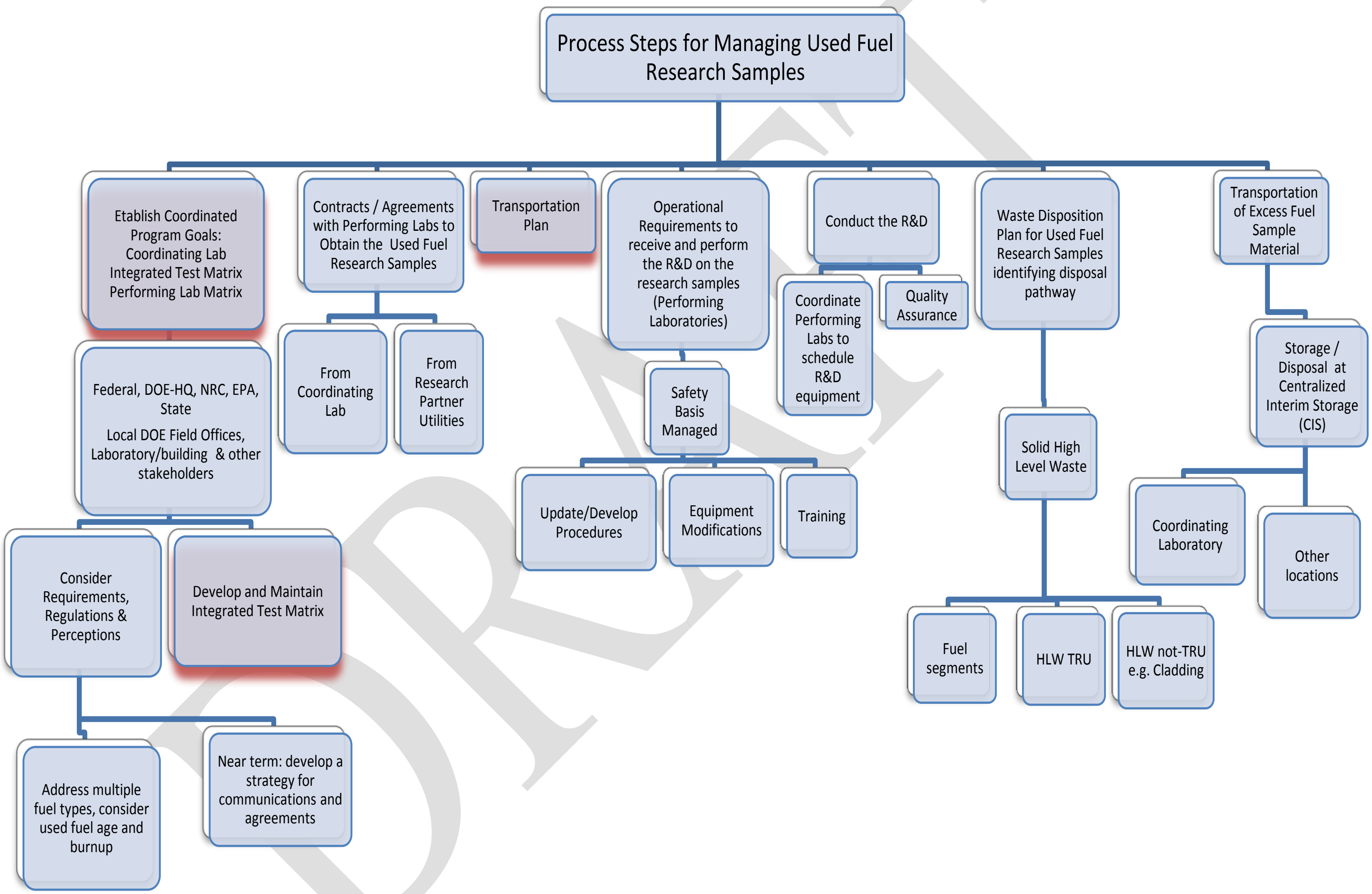

Figure 5.1. Example Process Steps for Establishing and Integrated System for UNF Research Samples and Wastes (highlighted areas indicate focus areas for next steps)

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Appendix A: Review of Gap Analysis to Support Extended Storage of UNF and Used Nuclear Fuel Storage and Transportation Data Gap Prioritization

The following is an excerpt from the Gap Summary report which is frequently cited in the present report. The excerpted material is provided as a convenience to the reader to provide context for the types of data and the measurements and test that will need to be performed as part of the RD&D for the UFD program. Information regarding the anticipated size of fuel samples that would be required has also been reproduced from the Gap Summary report and are provided for context. Table A-1 summarizes these data.

Used Nuclear Fuel Storage and Transportation Data Gap Prioritization FCRD-USED-2012-000109 April 30, 2012, excerpts from the Executive Summary

The U.S. Department of Energy Office of Nuclear Energy (DOE-NE), Office of Fuel Cycle Technology, has established the Used Fuel Disposition Campaign (UFDC) to conduct the research and development activities related to storage, transportation, and disposal of used nuclear fuel and high-level radioactive waste. The mission of the UFDC is to identify alternatives and conduct scientific research and technology development to enable storage, transportation, and disposal of used nuclear fuel (UNF) and wastes generated by existing and future nuclear fuel cycles. The storage and transportation staff within the UFDC are responsible for addressing issues regarding the extended or long-term storage of UNF and its subsequent transportation. The near-term objectives of the storage and transportation task are to use a science-based, engineering-driven approach to develop the technical bases to support the continued safe and secure storage of UNF for extended periods, subsequent retrieval, and transportation.

While both wet and dry storage have been shown to be safe options for storing UNF, the focus of the program is on dry storage of commercial UNF at reactor or centralized locations. Because limited information is available on the properties of high burnup fuel (exceeding 45 gigawatt-days per metric ton of uranium [GWd/MTU]), and because much of the fuel currently discharged from today's reactors exceeds this burnup threshold, a particular emphasis of this program is on high burnup fuels.

The first step in establishing the technical bases for storage and transportation was to determine the technical data gaps that need to be addressed. The *Gap Analysis to Support Extended Storage of Used Nuclear Fuel* (DOE 2012a, referred to as the Gap Analysis) was prepared to document the methodology for determining the data gaps and to assign an initial priority (Low, Medium, High) of importance for additional research and development to close the data gaps. The analysis considered only normal conditions of extended storage. A revision of the Gap Analysis report is planned for fiscal year 2012 to include data gaps associated with transportation as well as some design-basis phenomena (e.g., design-basis seismic events) and accident conditions (e.g., cask tipover).

The Gap Analysis (DOE 2012a) identified six gaps associated with cladding and the container that were assigned a High priority for additional research and development. An additional 11 gaps associated with cladding, fuel assembly hardware, neutron poisons, the container, and the concrete overpack or pad, were also identified and assigned a Medium priority. Numerous Low priority data gaps affecting the potential degradation of systems, structures, and components (SSCs) were also identified. Six cross-cutting data gaps (not specific to just one SSC) were identified and each was assigned a High priority.

Given limited budgets, the need to address current industry needs for licensing or renewing licenses for independent spent fuel storage installations (ISFSIs), and the need to address the recommendations of the Blue Ribbon Commission on America's Nuclear Future, it is necessary to further refine and prioritize those gaps assigned a Medium or High priority. The primary purpose of this report is to document the methodology and results of a more quantitative analysis used to prioritize the Medium and High priority data gaps from the initial Gap Analysis (DOE 2012a). One additional data gap, stress profiles, is included in this analysis to address the gaps associated with transportation, some design-basis phenomena, and accident conditions during extended storage. These gaps will be added to the planned revision of the gap analysis. To better facilitate the prioritization in this report, some of the data gaps were further refined. For example, the monitoring data gap was split into monitoring the internal canister/cask of the dry cask storage system (DCSS) and monitoring of the exterior, to include interrogation of the closure welds. Subcriticality was also split into burnup credit and moderator exclusion gaps to better address the different approaches for each method.

In order to develop the appropriate ranking or scoring criteria, it is important to identify the relevant considerations for the proposed research and development. The two primary considerations are the timing of data needs, and the importance to licensing or to program development. Individual metrics for these two considerations were developed and each gap was scored against these metrics. For the timing of data needs, consideration was given to whether the data need was imminent to support current activities or as a prerequisite for addressing another gap near-term to support license renewals for storage or to support transportation licenses, long-term to support extended storage and subsequent transportation, or to facilitate future waste management needs. The importance to licensing considered the likelihood of occurrence, the consequences of the degradation, and the difficulty for remediation. The scoring of cross-cutting gaps is more subjective than of SSC-specific gaps. The cumulative scores for each gap were then compared and prioritized. Importance of timing (when the data or model are needed) was given slightly higher importance than the importance to licensing. The gaps and their respective rankings are provided in Table S-1. The priorities and rankings reflect the needs of the DOE-NE program, with a focus on the entire waste management cycle, including potential reprocessing or geologic disposal; it is possible that the priorities reflecting the needs of the U.S. nuclear industry or of regulatory agencies may be different.

Options for closing each of the gaps following a science-based, engineering-driven approach are presented in Appendix A. Not all options need to be addressed in order to close a gap. Many of the gaps exist simply because little or no data exist. As more data are gathered, a determination will be made as to whether the gap is still important, if it can be considered closed, if other gaps need to be identified, and if the prioritization of the gaps needs to change. The options presented are at a very high-level; more detail will be provided in the gap-specific test plans to be developed.

Two different types of test are listed in the table, Separate Effects Tests SET) and Small-scale Tests. There definition is provided below. Some of the tests are done on full ISFSI and casks, and others are done on experimental quantities of used nuclear fuel. The top data gap prioritizations, (ranked as 1-5) are grouped together (shaded in yellow). A few of them require multiple rods to a few assemblies. The next set of gap prioritization; (6-10) require more UNF (as highlighted in green) and the detailed gap-specific test plans will address the amount of research quantities needed to perform the tests. This will require planning for research sample waste disposal as well. Data gap prioritization (11-14) are grouped together (shaded in orange) and the tests that require UNF are highlighted in green in Table A-1 below.

A-1.1 Separate Effects Tests (SET)

The purpose of SET is to identify the effects of individual variables on the degradation mechanism or gap. SET are typically performed on small material specimens to accommodate a large number of samples and a large testing matrix. In the case of UNF cladding, which will by nature have radiation damage, an oxide and/or crud layer, and contain hydrides, it is difficult to determine the effect of just one parameter on the cladding behavior. SET using surrogates with only one of those characteristics can be used to determine the effect from a single variable. However, it is necessary to show that the SET results are applicable to the integrated system. Still, SET can enable accelerated aging tests and provide insights into long-term behavior, even when not all conditions are prototypic.

A-1.2 Small-scale Tests

Small-scale tests are defined as those that are intermediate in size to the SET samples and the engineering-scale demonstration. Small-scale experiments are designed to investigate and test the integral effects of multiple components or variables together. For the case of UNF, most SET will be performed on small segments up to a single rod. The demonstration is meant to be a full-size cask loaded with dozens of assemblies. Small-scale testing is envisioned to range from multiple rods to a few assemblies.

Table A.1 Summary of Technical Gaps and Fuel Sample Needs

Data Gap Prioritization	**Rank**	**Types of Test Recommended**	**Expected Material Required for Tests**
Thermal Profiles	1	Small-scale Tests	Multiple Rods to a few Assemblies.
Stress Profiles	1	Both SET and Small-scale Tests	SET needs Fuel Assemblies irradiated or unirradiated on shaker table. Small scale test may use scaled down model with shortened fuel rods in a cask.
Monitoring – External	2	Both SET and Small-scale Tests	SET needs full ISFSI and cask for surface environment. Cooperation with EPRI for small scale test to simulate the environment the equipment experiences in the field.
Welded Canister – Atmospheric Corrosion	2	Both SET and Small-scale Tests	SET uses small samples. Small-scale testing may include sections of a full-sized canister.
Fuel Transfer Options	3	SET and Small-scale Tests if required	Multiple full length rods.
Monitoring – Internal	4	Both SET and Small-scale Tests	SET via laboratory-scale experiments. Once equipment is developed, test at INL site on CASTOR V/21 and REA-2023 casks when they are opened.
Welded Canister – Aqueous Corrosion	5	Both SET and Small-scale Tests	SET and Small-scale Tests start with those developed for Atmospheric Corrosion above, and are extended to Aqueous conditions, so uses small samples and sections of a full-sized canister.
Bolted Casks – Fatigue of Seals and Bolts	5	No new tests are proposed	DOE will collaborate with those in the international community already performing similar R&D.
Bolted Casks – Atmospheric Corrosion	5	No new tests are proposed	However, if the bolted casks at INL are opened, the bolts and seals should be examined for signs of corrosion.
Bolted Casks – Aqueous Corrosion	5	No new tests are proposed	However, if the bolted casks at INL are opened, the bolts and seals should be examined for signs of corrosion.

Table A.1. (contd.)

Data Gap Prioritization	Rank	Types of Test Recommended	Expected Material Required for Tests
Drying Issues	6	Small-scale Tests	Multiple Rods or Assemblies.
Burnup Credit	7	Small-scale Tests	Samples from multiple rods.
Cladding – H2 Effects: Hydride Reorientation and Embrittlement	7	Both SET and Small-scale Tests	Cladding with and without fuel and full length rods.
Neutron Poisons – Thermal Aging	7	Both SET and Small-scale Tests	SET uses small samples tested in a variety of conditions. Small-Scale tests can be with small amount of UNF cladding or with a neutron source and heaters.
Moderator Exclusion	8	Small-scale Tests	Multiple canister overpacks, canisters, and casks with multiple closure systems.
Cladding – H2 Effects: DHC	9	Both SET and Small-scale Tests	Cladding with and without fuel and full length rods.
Examination of the Fuel at the INL	10	SET and Small-scale tests not applicable	Strictly validation of modeling specific to CASTOR V/21 and REA-2023 casks.
Cladding – Creep	11	Both SET and Small-scale Tests	Cladding with and without fuel and full length rods.
Fuel Assembly Hardware – SCC for Lifting Hardware and Spacer Grids	11	Both SET and Small-scale tests	SET for hardware is part of the SET for unirradiated fuel that will be placed in a canister. Small-scale tests will be done with an instrumented scaled down model with shortened fuel rods in a cask.
Neutron Poisons – Embrittlement	11	Both SET and Small-scale Tests	SET uses small samples tested in a variety of conditions. Small-Scale tests can be with small amount of UNF cladding or with a neutron source and heaters.
Cladding – Annealing of Radiation Damage	12	Both SET and Small-scale Tests	Cladding with and without fuel and full length rods.
Cladding – Oxidation	13	Both SET and Small-scale Tests	Cladding with and without fuel and full length rods.

Table A.1. (contd.)

Data Gap Prioritization	**Rank**	**Types of Test Recommended**	**Expected Material Required for Tests**
Neutron Poisons – Creep	13	Both SET and Small-scale Tests	SET uses many small samples tested in a variety of conditions. Small-Scale Tests can be with small amount of UNF cladding or with a neutron source and heaters.
Neutron Poisons – Corrosion (blistering)	13	Both SET and Small-scale Tests	SET uses many small samples tested in a variety of conditions. Small-Scale Tests can be with small amount of UNF cladding or with a neutron source and heaters.
Overpack – Freeze–Thaw	14	Both SET and Small-scale Tests	SET consists of NDE for monitoring and inspecting overlying concrete and embedded steel at existing ISFSIs. Small-scale Tests exposes concrete to other aging and freeze-thaw and rebar corrosion.
Overpack – Corrosion of Embedded Steel	14	Both SET and Small-scale Tests	SET consists of NDE for monitoring and inspecting overlying concrete and embedded steel at existing ISFSIs. Small-scale Tests exposes concrete to other aging and freeze-thaw and rebar corrosion.

Appendix B: Example Map Locating Potential Performing Laboratories and Utility Research Partners

A brief study was performed to identify nuclear power plants located with a 75-mile radius of the national laboratories. The primary objective was to examine the potential complexity of a transportation route linking the laboratories and sources for retrieval of UNF rods for use in the UFD program.

Figure B. 1 Example of a Transportation Route Linking National Laboratories and Potential Utility Research Partners