Status and Path Forward for the Department of Energy Used Fuel Disposition Storage and Transportation Program - 12571

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ABSTRACT

The U.S. Department of Energy, Office of Nuclear Energy (DOE/NE) has sponsored a program since Fiscal Year (FY) 09 to develop the technical basis for extended dry storage of used fuel. This program is also working to develop the transportation technical basis for the transport of used fuel after the extended storage period. As this program has progressed, data gaps associated with dry storage systems (e.g., fuel, cask internals, canister, closure, overpack, and pad) have been identified that need to be addressed to develop the technical bases for extended storage and transportation. There has also been an initiation of experimental testing and analyses based on the identified data gaps.

The technical aspects of the NE program are being conducted by a multi-lab team made up of the DOE laboratories. As part of this program, a mission objective is to also collaborate closely with industry and the international sector to ensure that all the technical issues are addressed and those programs outside the DOE program can be leveraged, where possible, to maximize the global effort in storage and transportation research.

INTRODUCTION

In the summer of 2009, the DOE Office of Nuclear Energy (DOE/NE) initiated a program to support the development of the technical basis to justify extended dry storage of used nuclear fuel (UNF) past the regulatory time limit of 40 years. In addition, the program is evaluating the technical issues associated with the ability to transport UNF after extended storage.

Several factors point to the need for this work. First, the decision to cease the licensing process for the Yucca Mountain repository has the effect that UNF will stay in storage much longer than had been anticipated. It is now expected that UNF will need to remain in licensed storage configurations past the regulatory licensing period of 40 years. Material degradation issues of the entire UNF storage system must be well understood in order to make the technical arguments that UNF can be safety and securely stored for extended periods of time. Second, much of the earlier technical and demonstration work done to evaluate material degradation issues associated with UNF in storage was done using low burnup fuel (i.e., < 45 Gigawatt-days/Metric Ton Uranium [GWD/MTU]). Over the past 20 years, reactor operators have increased fuel burnups well past 45 GWD/MTU to the point that it has now become common practice. There is limited material property data for high burnup fuel in the open literature that can be used to demonstrate UNF performance in long term storage. Third, external reviews have pointed to the need to address extended storage of UNF. In particular, the Blue Ribbon Commission on America's Nuclear Future (BRC) has published draft recommendations [1] identifying the need to address the management of extended storage of UNF.

The conduct of the work in the DOE/NE program is divided into six control accounts, based on the technical work that is being addressed:

- Research and Development (R&D) Investigations
- Engineered Materials Experimental

- Field Testing
- Engineering Analysis
- Transportation
- Security

The status and future plans for the work being conducted under these six control accounts follows.

DISCUSSION

The primary objective of this program is to develop the technical basis to justify extended storage of UNF past the regulatory time limit of 40 years and to demonstrate that UNF is retrievable and has the integrity to withstand the rigors of the transportation environment to be shipped once the storage period is over and the UNF is shipped.

A science-based, engineered approach has been adopted to ensure that implementation of the program will be done in an efficient, yet comprehensive manner. Analytical, experimental, and demonstration programs by their nature are expensive and resources are limited. This approach, as shown in Figure 1, will provide the degree of depth across multiple engineering disciplines necessary to meet the stated objectives, with recognition that the R&D needs to go only to the point of development that there is sufficient understanding to make the technical argument for storage license extension and transportation.

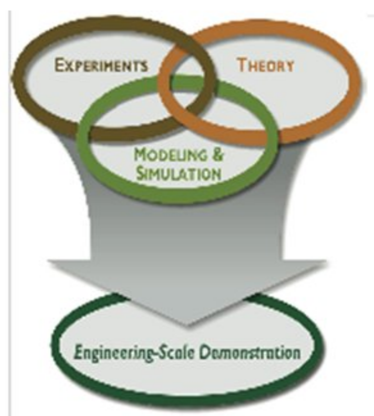

Fig 1. Science-based, engineering driven approach

The implementation of the science-based, engineering approach is realized with the six control accounts. These controls accounts provide the management structure to conduct the work in an integrated fashion that maximizes the efficiency and effectiveness in meeting the program goals.

A brief status and discussion of future plans are discussed are provided for each control account.

R&D Investigations

The goal of the R&D Investigations control account is to identify and prioritize the gaps that need to be addressed for supporting the development of the technical basis for extended storage and subsequent transportation. In addition, having identified the gaps, this control account is tasked with working with the other control accounts to identify how and where the work gets done.

The first objective of this task has been realized; the identification and prioritization of the technical data gaps. An 18 month effort was conducted to comprehensively develop functional requirements, conduct literature searches, hold workshops with industry and the regulator, and collaborate with international groups to identify and vet a list of high, medium, and low priority gaps that need to be addressed to successfully meet the program objectives. The principal functional requirement in this review was assessment of the impact of addressing the identified gap on the licensing process. If the gap was deemed to have a large impact on the ability to extend the storage license of the storage system, or to impact the ability to transport UNF, the gap was assigned a high priority relative to other gaps. In addition, the entire storage system was evaluated; UNF, baskets, neutron poisons, canisters, overpacks, closures, and the concrete pad.

Table I presents the list of high and medium priority gaps that have been identified in this process.

Table I. Identified high- and medium- technical data gaps for extended storage and transportation

Component	Degradation Mechanism	Importance of R&D	Approach to Closing Gaps
Cladding	Annealing of radiation damage	Medium	Long-term, low temperature annealing will be analyzed through advanced modeling and simulation with some experimental work to support the model.
	H_2 effects: embrittlement and reorientation	High	A comprehensive experimental and modeling program to examine the factors that influence hydride reorientation will be performed, with a focus on new cladding materials and high burnup fuels. Additional experimentation and modeling to provide the link between unirradiated and irradiated cladding performance will be initiated.
	H_2 effects: delayed hydride cracking	High	Experimental work combined with modeling will be initiated.
	Oxidation	Medium	Experimental work to determine the mechanism for the rapid cladding oxidation observed will be initiated.
	Creep	Medium	Long-term, low-temperature, low-strain creep will be analyzed through advanced modeling and simulation with some experimental work to support the model.
Fuel Assembly Hardware	Corrosion (stress corrosion cracking)	Medium	Because the fuel assembly hardware components of concern are the same or similar to those that also serve as cladding, cladding tests and analyses will be utilized.
Neutron Poisons	Thermal aging effects	Medium	Development of accurate source term, radiation, and thermal profiles is needed. Experimental work and modeling together in collaboration with universities under the Nuclear Energy University Program (NEUP) will be initiated. Collaboration will be initiated with the Disposal task within the DOE/NE Used Fuel Disposition Program (UFDP) performing corrosion testing on similar materials.
	Creep	Medium	
	Embrittlement and cracking	Medium	
	Corrosion (blistering)	Medium	

Container (Welded Canister)	Atmospheric corrosion (including marine environment)	High	Analyses of the conditions that will exist on the cask and canister surfaces, bolts and seals will be performed. Collaboration with the Electric Power Research Institute (EPRI)-led Extended Storage Collaboration Program (ESCP) and International Subcommittee will be initiated. Collaboration with the Disposal task within the UFDP performing corrosion testing on similar materials will be initiated.
	Aqueous corrosion	High	
Container (Bolted Casks)	Thermomechanical fatigue of seals and bolts	Medium	
	Atmospheric corrosion (including marine environment)	High	
	Aqueous corrosion	High	
Overpack	Freeze–thaw	Medium	Development of detailed aging management programs will be performed. Monitoring tasks to provide the means for early detection will be initiated.
	Corrosion of embedded steel	Medium	

FY12 efforts will focus on assessing these identified gaps with similar gap analyses performed by the U.S. Nuclear Regulatory Commission (NRC) and the Nuclear Waste Technical Review Board (NWTRB). In addition, this work will be used to inform the technical direction for the other control accounts. In particular, FY12 testing work has already been started under the Engineered Materials Experimental Control Accounts based on the identified data gaps.

Engineered Materials Experimental

This control account is new in FY12 and is a direct result of the completion of the data gap work discussed above. Two experimental programs are underway; one at Argonne National Laboratory (ANL) and one at Oak Ridge National Laboratory (ORNL) to investigate hydride effects in UNF cladding. This is identified as a high priority gap in Table I.

At ANL, ring compression tests are being conducted on high burnup cladding to assess the hydride effects on the material strength for M5® cladding based on static load tests. These tests augment earlier work by ANL for the NRC on different cladding material; Zry-4, and Zirlo®. Figure 2 shows the Instron 8511 test setup for the ring compression tests.

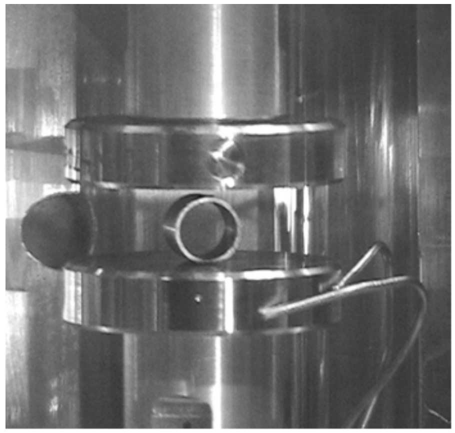

Fig. 2. Instron 8511 test apparatus set-up for ring compression tests

Two series of tests were conducted on M5® cladding that had burnups of 62 and 68 GWD/MTU under varying hoop stress and temperature conditions to assess the conditions for radial hydride formation and to estimate the Ductile to Brittle Transition Temperature (DBTT). Conclusions that are drawn from these tests are: 1) lowering peak drying stress from 140 MPa to 110 MPa has a relatively small effect on radial hydride formation and consequently DBTT (decreased from 80° C to 70° C), 2) there is significant variation in effective radial hydride length (i.e., the radial hydride continuity factor – RHCF) in both the circumferential and axial directions, and 3) the extent of wall cracking varies along the axis of the compressed ring.

The second test program just beginning this FY will be conducted at ORNL and will evaluate the effects of hydride embrittlement on unirradiated cladding. Unirradiated Zry-4 cladding will be doped with hydrogen in an autoclave and then placed in the ORNL High Flux Isotope Reactor and pulsed with neutrons to a level similar to what a high burnup fuel assembly would receive during normal reactor life. Tests will then be conducted on the cladding and compared to the ANL tests on irradiated cladding. The objective is to assess similarities or trends between the two conditions. If trends can be established, further testing on unirradiated cladding can be pursued in a much more efficient and cost-effective manner than continued testing with irradiated cladding.

Field Testing

This control account is new in FY12 and is focused on fielding near-term tests that address the technical data gaps that have been identified. In particular, this testing will be focused on larger scale systems effects types of tests, as opposed to the single effects types of tests that are being conducted in laboratory conditions in the Engineered Material Experimental control account.

There are two main objectives in FY 12 that are focused on fielding tests in the very near term. The first objective is to work with industry to assess fuel canister corrosion at utility storage sites that are located at or near coastal sites. The marine environment is identified as a high priority concern relative to corrosion and stress corrosion cracking of the stainless steel canisters used in many dry storage systems in the U.S. (Table I). This work is comprised of two parts; assessing the atmospheric conditions associated with coastal sites (humidity and salt content) and evaluation of the corrosion and stress corrosion cracking degradation mechanisms on the canisters in their dry storage configurations. The second part of this work will involve monitoring, inspection, and materials analyses to properly assess these degradation components in their storage conditions and environments. It is expected that close collaboration will occur between this program and with an industry program that is just beginning to work with utilities to field tests similar to what is envisioned for the DOE/NE program.

The second focus of this program is to assess the feasibility of fielding an initial storage demonstration platform at an existing licensed storage site. This storage platform would consist of a currently licensed dry storage cask with high burnup fuel as the payload. The objective is to begin storage of high burnup fuel early to start the clock running on some candidate used fuel for an extended term storage demonstration. The intent is to use a compatible cask and fuel at a particular utility that can then be moved to the utility storage pad (no over the road transportation) to begin a long term storage demonstration. Issues that need to be addressed are the type of storage cask to be used, the specific type of fuel to be stored, monitoring and inspection technologies to be employed (e.g., would cask lid penetrations be acceptable for monitoring fuel and environmental conditions inside the canister?).

Engineering Analysis

This is also a new control account for FY12. The objectives of the Engineering Analysis control account are threefold; 1) assess the types of technical data gaps that can be addressed using modeling and simulation, 2) integrate analysis with the on-going experimental work to provide validation and verification of the models being used, and 3) apply an Uncertainty Quantification methodology to the technical gaps identified in Table I to identify the work most effective in meeting the overall objectives of the program. That is, development of the technical basis for extended storage and subsequent transportation of UNF.

Early FY12 efforts have included an assessment of analytic capabilities across the DOE labs and preliminary identification of early applications for modeling and simulation efforts. For example, modeling and simulation of hydride behavior during the drying process and long term, low temperature creep have been identified as two early applications to apply modeling and simulation efforts. An effort has also been initiated to assess a can-in-can approach that envisions canistering up to four PWR assemblies in a single canister. Multiple smaller canisters could then be stored in a larger canister and overpack for extended storage. This approach could reduce downstream fuel assembly handling (i.e., improve ALARA conditions) and facilitate eventual disposal.

Transportation

Transportation to support the nation's storage of used fuel will become an increasingly important operational component of the management of used fuel. In support of a storage platform, testing of used fuel at hot cell facilities, and potential siting of one or more consolidated storage facilities, transportation of used fuel will need to occur. In particular, transportation of high burnup used fuel for the test and demonstration phases of the extended storage program will be required. There is currently no general regulatory position on certifying transport casks for transport of high burnup used fuels.

Several approaches are being pursued to provide the assurance that used fuel, particularly high burnup used fuel, can be transported after extended storage periods.

- Used fuel loading tests – Loading tests on used fuel component assemblies will be conducted in FY12 to determine actual loading conditions on fuel resulting from over-the-road normal transport conditions. While there has been much analysis done on package performance subjected to normal and hypothetical accident condition loadings, little is known about the forces that fuel rods actually experience during the transport operation. Given this load data and material property data from the R&D Investigations control account, finite element analyses can be conducted to determine if high burnup fuel, in its degraded state can withstand normal conditions of transportation. If so, hydride effects in cladding may not be as high a priority resulting in the ability to minimize the amount of cladding data that will need to be acquired in the R&D Investigations control account.

- Moderator exclusion - A non-mechanistic requirement in the transportation regulations [2] is that one must assume full moderation during a transportation accident. This places significant emphasis on fuel cladding integrity and geometry control of the used fuel configuration within the transportation package. However, the NRC has published guidance [3] on providing assurance that a transportation package can be designed to exclude moderation during a transportation accident. This effort is supporting work to develop the technical basis to demonstrate approaches for excluding moderation. Two focal points of this approach are to provide a separate containment barrier within the primary containment barrier and to provide a second set of independent seals for the primary containment barrier.
- Criticality Control – Analytic work is on-going to better understand margins of safety relative to criticality under the current transportation regulations. A spectrum of severe accident scenarios is being analyzed to compare estimates of k_{eff}. This work will provide a better understanding of the safety margins around criticality and the possibility to assess potential for allowing limited cladding damage or loss of geometry control without compromising assurance of sub-criticality during transportation.

Security

The Security control account is focused on assessing the security issues associated with extended storage and subsequent transportation of used fuel. There are two main security issues that discriminate extended storage from the regulatory storage period.

- Spent fuel threshold – 10CFR73 [4] stipulates that irradiated reactor fuel is exempt from enhanced physical protection measures if it has a radiation field > 100 Roentgen equivalent man (Rem)/hr at 3 ft. When the regulation was written, this dose rate was considered “self protecting” and was deemed safe from a sabotage perspective. As used fuel continues to age in a storage condition, the fuel will decay below this spent fuel threshold. Once it does, it becomes non-exempt from the regulations and must be protected at Category 1 or 2 levels. This will have a significant impact on existing licensed storage facilities.
- Material attractiveness – 10CFR73 does not discriminate form of material in establishing levels of protection for nuclear materials. Basically, Special Nuclear Material (SNM)[1] is assessed based on mass of SNM. If the mass of SNM is over the threshold, enhanced physical protection measures must be provided.

Both of these issues are being tracked within the current rule-making process at the NRC. As the NRC revises regulatory positions based on their technical analyses, the DOE program will assess the impact of these rule changes and provide guidance to support compliance with any new rules that may result.

Industry Collaborations

The NE program is closely aligned with similar industry efforts in order to maximize the impact of all work that is conducted under this program. The focus of the collaborations is under the aegis of the Electric Power Research Institute Extended Storage Collaboration Program (EPRI/ESCP). This program

[1] Strategic Special Nuclear Material SNM is defined in 10CFR73 as Uranium enriched to 20% or higher in U-235, U-233, or Plutonium.

is a volunteer group of organizations dedicated to development of the technical basis for extended storage and transportation. It is made up of representatives from industry (EPRI, Nuclear Energy Institute (NEI), utilities, cask and fuel vendors), the NRC, the NWTRB, the DOE, and the DOE laboratories.

This program is working to identify and prioritize technical data gaps to develop the technical basis for extended storage and transportation, as well as to begin leveraging programs to obtain early data to address these gaps. An effort to identify and prioritize data gaps from an international perspective will conclude in the early summer. This will provide a consensus document on important data gaps for storage systems used around the world. Second, FY12 efforts will focus on acquiring atmospheric and corrosion data for canisters in storage in coastal environments. Table I identifies canister corrosion and stress corrosion cracking in marine environments as high priority gaps.

CONCLUSION

The DOE/NE program is actively pursuing the development of the technical basis to demonstrate the feasibility of storing UNF for extended periods of time with subsequent transportation of the UNF to its final disposition. This program is fully integrated with industry, the U.S. regulator, and the international community to assure that programmatic goals and objectives are consistent with a broad perspective of technical and regulatory opinion. As the work evolves, assessments will be made to ensure that the work continues to focus on the overall goals and objectives of the program.

REFERENCES

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