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The High Burnup Confirmatory Data Project

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Introduction

Plans to design, license, construct and operate a commercial spent nuclear fuel repository in the United States have been delayed. As a result, storage times of spent fuel in licensed storage systems will need to be extended; in some cases, beyond their allowable license extension periods. While it is expected that the spent fuel in licensed storage systems will remain safe and secure for many decades, an effort is underway to provide confirmatory data to validate this understanding.

This expectation is based largely on an earlier storage demonstration project for low burnup fuels that took place in the U.S. in the late 1980's (Kessler 2002, McKinnon 1997). In the past several decades however, reactor operations have improved and become much more efficient, resulting in higher fuel burnups before discharge from the reactor. Higher fuel burnups impact discharged fuel component properties (e.g., higher hydrogen contents in the cladding, differences in pellet-clad interactions, higher internal rod pressures, etc.) Therefore, confirmation of fuel performance for extended periods of time for high burnup fuel (e.g., > 45 GWd/MTU) is desirable.

To address high burnup fuel performance during extended storage, the U.S. Department of Energy (DOE) entered into a contractual relationship with the Electric Power Research Institute (EPRI) and its partners (Dominion Power and AREVA) to stage a demonstration project to generate data and assess real time performance of HBU fuel in an NRC-licensed dry storage cask for 10 years.

Background

Two independent events led to the realization of the Confirmatory Data Project (CDP). First, improvements in reactor operations resulted in discharge of higher burnup fuels. It was recognized that the positive results from the earlier dry storage demonstration project was limited to spent fuel burnups < 35 GWd/MTU. With fuel being routinely discharged at burnups > 45 GWd/MTU, a current understanding of spent fuel degradation mechanisms in long term storage needed to be extended to these higher burnup fuels. To help address this gap, the U.S. Nuclear Regulatory Commission (NRC) issued Interim Staff Guidance, ISG-11, that provided a licensee guidance for evaluating high burnup spent fuel cladding characteristics under storage and transportation conditions (NRC 1999).

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The Electric Power Research Institute (EPRI) then published a report on the feasibility of conducting a high burnup storage demonstration program (EPRI 2003). This work was conducted under the Nuclear Energy Plant Optimization (NEPO) program and three options for conducting a high burnup dry storage demonstration program;

1. Option A – Augment Existing Examination Program
2. Option B – Utility Independent Spent Fuel Storage Installation (ISFIS) Followed by Laboratory Examination
3. Option C – Laboratory Storage and Examination

Evaluation of these options included estimated duration of project, evaluation of potential storage systems, assessment of periodic monitoring and inspections while in storage, post-storage fuel examination, and post-test disposal and cleanup. Time and cost for these options ranged from 5 years and $5M for Option A to 12 years and ~$20M for Options B and C. The conclusions of this report stated that there is a technical need due to the gap in fuel data for spent fuel with burnups > 45 GWd/MTU; there is interest from industry, the regulator, and the DOE; and there are resources available.

Second, the cessation of licensing activities in 2009 for the planned Yucca Mountain spent fuel repository immediately cast into question the ability to extend the licensing of existing storage systems. Without a firm date for beginning repository operations, it was reasonable to consider having the need to store spent fuel in their current systems for periods that exceeded their licensing terms. Without confirmatory data for these high burnup fuels in extended storage, it becomes problematic to quantitatively demonstrate fuel integrity for many decades.

In 2009, the DOE initiated an R&D program that was focused on supporting the development of the technical basis to support extended storage and subsequent transportation of high burnup spent fuel. The DOE national laboratory system provides the technical support to this program along with a strong collaborative effort with industry and the NRC. The first task under this program was to identify and prioritize the technical gaps needed to be addressed to build the technical data base that will be used to support future storage extension and transportation licensing activities. A comprehensive assessment of technical gaps and priorities for the DOE program are provided in (Hanson 2011, Hanson 2012). Areas of high importance included hydrogen effects on cladding; thermal and stress profiles; monitoring; stainless steel canister corrosion and stress corrosion cracking; general corrosion of bolts and seals for bolted closure systems; and cask drying after loading of the spent fuel.

Other organizations also provided independent gap assessments, including the Nuclear Waste Technical Review Board (NWTRB 2010), the Nuclear Regulatory Commission (NRC 2012), the Electric Power Research Organization (EPRI 2011), and the International Atomic Energy Agency (IAEA 2002). In addition, EPRI sponsored a comprehensive international gap assessment through their Extended Storage Collaboration Program (ESCP) (EPRI 2012). While there are differences in identified gaps and associated priorities in these studies, there is consistency across the reports in identifying high priority issues; in particular, hydrogen effects on cladding and corrosion issues associated with stainless steel canisters.

The NRC subsequently issued draft Interim Staff Guidance, ISG-24 Draft, for public comment that provided guidelines to conducting a high burnup dry storage demonstration program (FR 2013). This draft ISG provided guidance for gathering high burnup spent fuel data in extended storage conditions over an extended timeframe.

The work discussed in this section provided the confidence across multiple organizations that conduct of a dry storage demonstration program would provide the necessary confirmatory data to support extended storage licensing applications.

The High Burnup Confirmatory Data Project: Details

In April 2013, the DOE entered into a contract with EPRI to conduct the High Burnup Confirmatory Data Project. This project aligns quite closely to Option B of the 2003 EPRI feasibility report (EPRI 2003) on options for conducting a demonstration project for high burnup fuel.

For this project, EPRI is teaming with Dominion Power and Areva (specifically, Areva Federal Services, Areva Transuclear, and Areva Fuels). From the DOE side, technical support is provided by several of the DOE national laboratories.

In general, the objectives of this project are to monitor and inspect high burnup spent fuel that is placed in an NRC-licensed dry storage cask for a period of approximately 10 years. This will provide the confirmatory data needed to support extended licensing considerations. The industry team that was chosen is especially well suited to address these project objectives. Important technical aspects of this project include:

- The high burnup fuel will be selected from the Dominion North Anna spent fuel pool. All the fuel will be PWR and will include a range of high burnups and cooling times, as well as the major cladding types; Zr-4, Zirlo, and M5.
- The cask that will be used is an NRC-licensed TN-32B. Figure 1 is a picture of a TN-32 cask.
- Thermal lances with integrated thermocouples will be a permanent part of the storage cask. These lances will require a lid penetration and will trace cask internal temperature readings on a continuous basis.
- Gas samples will be taken soon after the cask has been loaded and completely dryed as well as three times over the 10 year period that the cask is operating on the storage pad. This sampling will specifically look for any indication of water (e.g., incomplete drying) and fission gasses (e.g., potential fuel rod leaks).
- Individual rods will be pulled from similar (sister) assemblies. These rods will be sent to a DOE laboratory to undergo separate effects testing to determine initial material property and physical conditions of the rods. These initial conditions will then be compared with testing results on the stored fuel after the extended drying period. The transport of the sister rods and subsequent testing are not a part of this contract.
- A license amendment will be prepared for NRC review and approval to cover the lid penetration as well as the specific collection of high burnup fuel assemblies.
- After approximately 10 years, the cask will be shipped to a DOE laboratory to inspect and conduct testing on the spent fuel.

Figure 1. TN-32 Dry Storage Cask

The development of the test plan, selection of fuel assemblies and sister rods, and the identification of monitoring and inspection techniques and processes, are focused on gathering the necessary data discussed in the preceding section to build the technical data base to support extended licensing of dry storage systems in the U.S. This assessment must balance the desire to obtain as much detailed information and data possible to support the science aspect of the project with the operational and licensing constraints inherent in a licensed, operating nuclear facility.

The High Burnup Confirmatory Data Project: Status

The CDP planning has progressed remarkably well during the two years the contract has been in place. The first important document to be completed is the Final Test Plan (EPRI 2014). Before being finalized, the draft was issued for public comment. A total of 189 comments were received and were addressed before the final document was issued.

Placement of the thermal lances and resultant location of the thermocouples within the lances and their position relative to the spent fuel and location within the basket was an early activity. This activity was important to locate the thermocouples in strategic positions to optimize the thermal data that will be collected. Seven lances will penetrate the closure lid. 9 thermocouples will be threaded into each lance, providing 63 temperature collection locations. These locations will collect data from spent fuel assemblies of interest, as well as provide a comprehensive data set of temperature characteristics within the basket and internal cavity of the cask as a function of time.

One of the major tasks during this period was the selection of the specific fuel assemblies for the CDP. As stated in the Introduction, the primary parameters were that the spent fuel should be high burnup (i.e., > 45 GWd/MTU), all the various PWR cladding types should be included (i.e., Zr-4, low tin Zr-4, Zirlo, and M5), and the cladding temperature during loading, drying, and storage should reach as close as possible the NRC limit of 400º C. This temperature criterion is important to drive as much as the incumbent hydrogen in the cladding back into solution so that when the rod cools and the hydrogen precipitates back into a solid, the maximum possibility of hydride re-orientation will occur.

Initial selection of the fuel was based on these criteria. Following the selection, detailed thermal analyses were conducted to estimate peak cladding temperatures. Initial results were surprising in that, even with high burnup fuel, peak cladding temperatures only reached ~300º C. This is due to the design of the TN-32 and its ability to shed heat very effectively through conduction pathways. After several iterations, the final assembly identification and configuration inside the TN-32B basket was decided. High burnup fuel assemblies with shorter in-pool cooling times were substituted for longer cooled high burnup fuel. This resulted in maximum cladding temperatures of about 340º C (Brookmire). While the maximum cladding temperature is still somewhat lower that the desired 400º C, this was the maximum that could be attained as this configuration resulted in a limiting temperature of 149º C for the neutron shield on the external surface of the cask. The total heat load generated by the spent fuel in the cask is 37kW.

Recent work that has just been completed is the identification of specific sister rods that will be pulled from assemblies that have like characteristics to the assemblies that will be loaded into the TN-32B. A total of 25 rods were selected to conduct the separate effects tests. This inventory of sister rods is made up of 9 Areva M5 rods, 9 Westinghouse Zirlo rods, 4 Westinghouse low-tin Zr-4 rods, and 3 Westinghouse Zr-4 rods. The Areva M5 rods were pulled from their assemblies at the North Anna Site in January 2015. The schedule for the Westinghouse rods is to pull them in June 2015.

Under the contract, a Design and Licensing Basis Document (DLBD) has been written to support the up-coming license amendment request (LAR) (Brookmire). These documents are necessary to process the

NRC review and approval for amending the current TN-32 storage license. Aspects of the amendment include the lid design to account for the thermal lance penetrations, a new criticality analysis, a new thermal analysis to account for the higher heat loads, and a new radiological analysis to account for the higher burnup fuel.

The High Burnup Confirmatory Data Project: Near-term schedule

The schedule of recent and up-coming important milestones for the CDP includes (Brookmire):

- December 2014: Completion of the Design Basis Licensing Document
- January 2015: Areva M5 sister rods pulled
- June 2015: Westinghouse low-tin Zr-4, Zr-4, and Zirlo rods pulled
- July 2015: Submit License Amendment Request to the NRC
- First Quarter 2016: Ship sister rods to DOE laboratory
- January 2017: NRC review complete
- March 2017: TN-32B cask delivered to North Anna site
- June 2017: Dry run and functional tests complete
- July 2017: Cask loading complete – begin initial monitoring
- August 2017: Cask moved to the storage pad – begin long term monitoring

The scheduling of this project was also subjected to the need of balancing the desire to accelerate the data collection efforts to support the science with the operational and licensing requirements of the North Anna site. These dates were chosen as earliest opportunities to conduct the site work without conflicting with the normal operational requirements at a nuclear facility.

Conclusions

The CDP is designed to provide the necessary confirmatory data to support extended storage licensing for dry storage systems containing high burnup fuel. The data needed has been identified through a decades long process that included an early storage demonstration for low burnup fuels, succeeding R&D associated with high burnup fuels, and regulatory guidance developed as a result of the R&D. This portfolio of work provides the confidence that the data collected from the CDP, coupled with the separate effects tests on the sister rods, will confirm our understanding of fuel behavior over long storage periods and justify the technical basis for license extension for storage.

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