Division of Spent Fuel Storage and Transportation
Interim Staff Guidance-24, Revision 0

The Use of a Demonstration Program as a Surveillance Tool for Confirmation of Integrity for Continued Storage of High Burnup Fuel Beyond 20 Years

Issue:

The U.S. Nuclear Regulatory Commission (NRC) has determined that long term storage and transportation of high burnup fuel is safe. This determination does not relieve an applicant of the responsibility to provide information that demonstrates reasonable assurance that their application meets all pertinent NRC requirements relative to cladding integrity. This Interim Staff Guidance (ISG) document provides guidance to the staff for reviewing if a demonstration of high burnup fuel (HBF)[1] has the necessary properties to qualify as one method that an applicant might use in license and certificate of compliance (CoC) applications to demonstrate the integrity of HBF for continued storage. This guidance is not a regulatory requirement. Alternative approaches may be used to demonstrate safety and compliance, as appropriately justified by an applicant.

Title 10 of the Code of Federal Regulations (10 CFR) Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste," requires that storage of the waste meet various criteria. One criterion requires the spent fuel cladding be protected during storage against degradation that leads to gross ruptures, or not pose operational safety problems with respect to its removal from storage (see 10 CFR 72.122(h)(1)). Additionally, storage systems must be designed to allow ready retrieval of the waste for further processing or disposal (see 10 CFR 72.122(l)).

Discussion:

The experimental confirmatory basis that low burnup fuel (≤45 GWd/MTU) will maintain its integrity in dry cask storage over extended time periods was provided in NUREG/CR-6745 (Ref. 1), "Dry Cask Storage Characterization Project—Phase 1; CASTOR V/21 Cask Opening and Examination" and NUREG/CR-6831 (Ref. 2), "Examination of Spent PWR Fuel Rods after 15 Years in Dry Storage."

Certification and licensing HBF for storage was permitted for an initial 20-year-term using the guidance contained in ISG-11, Rev. 3, (Ref. 3) which was based on short term laboratory tests and analysis that may not be applicable to the storage of HBF beyond 20 years, particularly with the current state of knowledge regarding HBF cladding properties. (Ref. 4)

One concern stated in ISG-11, Rev. 3, was the potential detrimental effects, such as reduced ductility, of hydride reorientation on cladding behavior. Research performed in Japan and the United States indicated that: 1) hydrides could reorient at a significantly lower stress than previously believed (Ref. 5, 6), and 2) the radial hydrides could raise the cladding ductile-to-brittle transition temperature (DBTT) enough to affect the ability of the cladding to withstand stress without undergoing brittle failure (Ref. 4). This phenomenon might influence the ability to retrieve HBF on a single assembly basis. Circumferential zirconium hydrides in the fuel cladding

[1] Note that the terms "high burnup fuel" and "low burnup fuel" are terms of convenience and do not indicate that fuel properties undergo a significant change as burnup is increased from 44 GWd/MTU to 45 GWd/MTU.

regions would dissolve into the fuel cladding during drying and reprecipitate (reorient) as radial hydrides as the fuel cladding cooled. Thus, fuel cladding with radial hydrides that is below a DBTT may be too brittle to retrieve on an assembly basis. ISG-11, Rev. 3, provided guidance on maximum temperature and internal rod pressure to mitigate hydride reorientation which is applicable to HBF during the initial 20-year storage, as the decay heat of HBF is expected to maintain cladding temperatures above a DBTT (typically ~ 200°C).

There is no evidence to suggest that HBF cannot similarly be stored safely and then retrieved for time periods beyond 20 years. Additional confirmatory data or a commitment to obtain data on HBF and taking appropriate steps in a learning aging management plan (AMP) will provide further information that will be useful in assuring the storage and retrievability of HBF for extended durations beyond 20 years.

A demonstration program is one acceptable method for an applicant to provide additional data and evidence in demonstrating compliance with the cited regulations for storage of HBF for periods of greater than 20 years by:

1. Confirming the expected fuel conditions, based on technical arguments made in ISG-11, Rev. 3, after a substantial storage period that is sufficiently long (~ 10 years). This confirmation will allow extrapolation of its findings to the storage duration of interest (i.e., beyond the initial license term of 20 years.) The behavior of the cladding for the renewal term will depend on its physical condition at the end of the initial 20 year storage period.
2. Providing data for benchmarking, confirming predictive models, and updating aging management plans.
3. Confirming the time-limited aging analyses (TLAA) cladding creep predictions that are the basis for the guidance recommendation for the maximum temperature in ISG-11, Rev. 3 are not exceeded, and that sufficient creep margin exists for the extended storage period.
4. Determining the system is sufficiently dry to eliminate moisture driven degradation from consideration.
5. Providing operational experience on the fuel behavior and drying procedure as input to an AMP on the behavior of the fuel.
6. Identifying any aging effects that may be missed through short-term accelerated studies and analyses.

Monitoring of the fuel temperatures, gas composition, and other conditions in the canister or cask combined with physical examination of the fuel at periodic intervals should be able to provide confirmation that:

1. The models of the phenomena used for the first 20-year predictions can be used for the TLAA beyond 20 years.
2. The condition of the fuel, after an appropriately long period of storage, does not degrade.
3. New degradation mechanisms of the fuel have not surfaced.

Extrapolation outside the recorded data carries risk, but that risk can be minimized if the length of the extrapolation is reduced and those extrapolations are updated as the demonstration continues to monitor and measure fuel properties.

Regulatory Basis:

- 10 CFR 72.122(h)(1) *Confinement Barriers and Systems.* The spent fuel cladding must be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage. This may be accomplished by canning of consolidated fuel rods or unconsolidated assemblies or other means as appropriate.

- 10 CFR 72.122(l) *Retrievability*. Storage systems must be designed to allow ready retrieval of spent fuel, high-level radioactive waste, and reactor-related greater than Class C waste for further processing or disposal.

Applicability:

This guidance applies to license and CoC applications for the storage of HBF for periods greater than 20 years. This guidance supplements the guidance given in NUREG-1927 on aging management for the interior of the cask. (Ref. 7)

Technical Review Guidance:

The applicant may use the results of a completed demonstration or an on-going demonstration if the conditions of the demonstration meet the requirements stated below for the fuels and conditions of storage for which the term is to be renewed. A description of the demonstration, as described in the AMP, shall be incorporated as an enforceable condition that is placed in the renewal CoC or site specific license. In either case, the demonstration must be in conjunction with a learning AMP as an acceptable means for confirming that the canister or cask contents satisfy the applicable regulations. Because limited AMP action can be taken inside a sealed canister, the AMP must be updated with new information from the demonstration program indicating unexpected adverse fuel behavior such as incomplete drying, fuel failure, or excessive cladding creep, when it becomes available. The update should include an analysis of the implications of unexpected behavior on safety and fuel retrievability, and a plan to mitigate any safety issues. The approach in this ISG can be applied to a generic demonstration program or a site/system specific program as long as the demonstration's parameters are reasonable and applicable to the applicant's fuel type and characteristics.

The technical review staff should ascertain that the following conditions are met if the demonstration is to be used by the applicant to support fuel assembly conditions for storage of HBF beyond 20 years and to be applicable to support a license or certificate application:

1. That the maximum burn-up of the fuel in the application is less than the burn-up of the fuel in the demonstration. If the burn-up is higher than that in the demonstration, the applicant should provide evidence, based on characteristics of the fuel, derived either from reactor rod qualification testing or other separate effects tests, that the demonstration fuel is reasonably characteristic of the stored fuel and the added burn-up will not change the results determined by the demonstration. Similarly, if there is a different cladding type used, arguments based on comparison of composition and fabrication technique (e.g., stress-relieved and annealed, recrystallized, etc.) should justify the use of the demonstration results.

2. If the applicant uses direct observations of the rod behavior to imply the condition of the rods in its system, either a) the temperatures in the demonstration must bound the temperatures in the application, or b) if the applicant uses predictive tools that have been confirmed by the demonstration, then the temperatures of the rods in the application do not have to be bound by the temperature of the rods in the demonstration. The temperature models used in the application should either be benchmarked a) against the demonstration temperature data, or b) against actual measured rod temperature data in the same temperature range.

3. If the applicant is using gas analysis or another gas detection method to establish the condition of the fuel, the interior of a demonstration canister or cask should be quantitatively monitored for, at a minimum, moisture, oxygen, and fission gas. The duration and frequency of the gas monitoring should be determined by analysis of the potential degradation. Gases should always be quantitatively monitored prior to opening of the canister. If the applicant claims that no galvanic degradation is feasible, then, if after drying, moisture is detected in the canister, moisture and hydrogen concentration should be monitored at a reasonable frequency to be determined by the applicant until the moisture disappears. Gas monitoring is not expected during movement of the canister. If the applicant is using the gas analysis to show no breaches would occur during transport, gas quantitative monitoring must be conducted before and after transport.

4. Cask internal temperature monitoring should be conducted at a frequency that is suitable for determining the temperature profile over the duration of the demonstration.

5. As practicable, some population of stored rods should be examined whenever the system is opened. These rods should be extracted from the fuel assembly to determine properties of the rods that affect degradation such as cladding creep, fission gas release, hydride reorientation, cladding oxidation, and cladding mechanical properties.

6. The demonstration program fuel shall include at least two full fuel assemblies. The assemblies may be reconstituted.

7. Data from the demonstration program must be indicative of a storage duration long enough to justify extrapolation to the total storage time requested but no less than 10 years if the data is to be used to support license extension from 20 – 40 years[2].

   As a minimum, the monitoring data from the demonstration must be available before the end of the current licensing period. If available, data from the examination of the rods should be cited in the applicant's analysis of the condition of the fuel.

[2] The initial license or certificate period is 20 years and renewal periods are up to 40 years. A demonstration is to provide that there was satisfactory performance during the first 20 years of licensed term and that the results could be extrapolated to support an additional 40 years of renewed license term. The staff agreed that a demonstration of ≤ 10 years storage duration is insufficient to support these goals

8. A learning AMP should be periodically re-evaluated given the current state of knowledge regarding the ability of HBF to meet the regulatory requirements while in dry cask storage. Licensing conditions should require updated AMPs to be submitted to the NRC whenever new data from the demonstration or other short-term tests or modeling results indicates potential degradation of the fuel or deviation from the fuel's expected behavior. Updates to AMPs will be subject to inspection.

Recommendations:

The staff recommends that NUREG-1927 (Ref. 7) be modified to add this guidance in Section 3.4.3, "Aging Management Activity" or other appropriate documentation being developed for the relicensing path forward for HBF.

Approved: **/RA/** **July 11, 2014**

Mark D. Lombard, Director
Division of Spent Fuel Storage
and Transportation
Office of Nuclear Material Safety
and Safeguards

Date

References:

1. NUREG/CR-6745, "Dry Cask Storage Characterization Project-Phase 1: CASTOR V/21 Cask Opening and Examination." Idaho National Engineering & Environmental Lab, September 2001.

2. NUREG/CR-6831, "Examination of Spent PWR Fuel Rods after 15 Years in Dry Storage." Argonne National Laboratory, September 2003.

3. Interim Staff Guidance - 11, Revision 3, "Cladding Considerations for the Transportation and Storage of Spent Fuel." U.S. Nuclear Regulatory Commission, November 2003.

4. M.C. Billone, T.A. Burtseva, and R.E. Einziger, "Ductile-to-Brittle Transition Temperature for High-Burnup Cladding Alloys Exposed to Simulated Drying-Storage Conditions," in the Journal of Nuclear Materials, Volume 433, Issues 1–3, pages 431–448, February 2013.

5. K. Kamimura, "Integrity Criteria of Spent Fuel for Dry Storage in Japan" Proc. International Seminar on Interim Storage of Spent Fuel, ISSF 2010, Tokyo Nov 2010, page VI3-1.

6. R.S. Daum, S. Majumbdar, Y. Liu, and M.C. Billone, "Radial-hydride Embrittlement of High-burnup Zircaloy-4 Cladding", Journal of Nuclear. Science and Technology, Vol. 43, No. 9, p.1054, 2006.

7. NUREG-1927, "Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance Final Report." U.S. Nuclear Regulatory Commission, March 2011.