Demonstrating the Safety of Long-Term Dry Storage – 13468

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ABSTRACT

Commercial nuclear plants in the United States were originally designed with the expectation that used nuclear fuel would be moved directly from the reactor pools and transported off site for either reprocessing or direct geologic disposal. However, Federal programs intended to meet this expectation were never able to develop the capability to remove used fuel from reactor sites – and these programs remain stalled to this day. Therefore, in the 1980s, with reactor pools reaching capacity limits, industry began developing dry cask storage technology to provide for additional on-site storage. Use of this technology has expanded significantly since then, and has today become a standard part of plant operations at most US nuclear sites. As this expansion was underway, Federal programs remained stalled, and it became evident that dry cask systems would be in use longer than originally envisioned. In response to this challenge, a strong technical basis supporting the long term dry storage safety has been developed. However, this is not a static situation. The technical basis must be able to address future challenges. Industry is responding to one such challenge – the increasing prevalence of high burnup (HBU) used fuel[1] and the need to provide long term storage assurance for these fuels equivalent to that which has existed for lower burnup fuels over the past 25 years. This response includes a confirmatory demonstration program designed to address the aging characteristics of HBU fuel and set a precedent for a learning approach to aging management that will have broad applicability across the used fuel storage landscape.

[1] Much of the used reactor fuel discharged today is HBU fuel (> 45 gigawatt-days per metric ton burnup), meaning the fuel was used in the reactor for 4 to 6 years. Previously, when the first dry casks were loaded, used fuel was discharged at burnups of less than 30 gigawatt-days per metric ton, corresponding to about 2 years of use in a reactor.

INTRODUCTION

Since the first dry cask storage systems were loaded in 1986, this innovative solution has become one of the nuclear industry's most impressive success stories. To date, over 1600 dry cask systems have been safely loaded and are storing over 18,000 metric tons of used fuel, approximately a quarter of the total US inventory [1]. These systems have performed the task of protecting public health and safety reliably and efficiently with no harmful release of radioactivity to the environment. Most of these systems are also designed to be transportable so that, once the federal government develops the capability to remove used fuel from reactor sites, the highly radioactive used fuel will not have to be repackaged for shipment.

As the dry cask storage industry successfully grew and matured, the alleviation of reactor pool capacity constraints was not the only problem being addressed by the technology. Beginning in 1984, the U.S. Nuclear Regulatory Commission (Commission or NRC), in response to a court ruling, began addressing the environmental impacts of used fuel accumulation on a generic basis. This was conducted through a succession of rulemakings (10 CFR Part 51) documenting the Commission's generic findings with regard to the federal government's capability to manage the country's nuclear waste (known as the "Waste Confidence" findings). The original findings, and subsequent updates in 1990 and 1999, were largely predicated on the Commission's confidence that the federal government would make good on its statutory and contractual obligation to dispose of used nuclear fuel in a timely manner. These findings were supported both by progress in the development of a repository for final disposal at Yucca Mountain, Nevada and industry's demonstrated ability to handle the material safely at reactor sites until Yucca Mountain would be ready.

In 2010, with the termination of the Yucca Mountain project putting the federal government's plans to remove used fuel from reactor sites back to square one, the NRC again updated its Waste Confidence findings. Reviewing the wealth of technical information that had been accumulated over a quarter of a century of dry cask storage experience, the Commission determined that used fuel could be safely stored at reactor sites for at least 60 years beyond the operating life of the reactor – which, when added to the 60 year operating life of most commercial reactors amounted to a statement that dry cask storage could be safely counted on for at least 120 years.

On June 8, 2012, the U.S. Court of Appeals for the District of Columbia, in response to suits brought by a number of states and other parties displeased with the prospect of such long term storage at reactor sites, remanded and vacated the Commission's 2010 Waste Confidence rule. Importantly, the court cited no deficiency with respect to the Commission's fundamental generic finding that used fuel could be stored on-site safely – including in dry cask storage – for an extended period of time. However, the court found that NRC had not performed an adequate environmental evaluation in three specific areas unrelated to dry cask storage as part of the rulemaking. The court determined that additional analyses of potential reactor pool fires and leaks are necessary and instructed the Commission to further evaluate the environmental impacts of a repository "never" being developed.

This court ruling is having a significant effect on the licensing of new nuclear projects. On August 7, 2012 the Commission suspended the issuance of new or renewed reactor licensing until the court decision could be addressed – a process which the Commission plans to complete by the fall of 2014.

As the NRC proceeds to address the court ruling, industry is continuing to provide for long term used fuel storage. The successful record of dry cask storage, and the steps that industry is taking to assure that this record can be extended far into the future, even as the nature of used nuclear fuel itself evolves, provide the necessary assurances that used fuel can continue to be safely managed until a repository becomes available, whenever that might be.

THE EXISTING TECHNICAL BASIS FOR LONG TERM STORAGE

Dry cask storage systems are robust structures with no moving parts. These systems incorporate multiple features to protect public health and safety. The foremost safety feature is the robust container itself: steel, steel-reinforced concrete, or steel-enclosed concrete 18 or more inches thick. The containers are extremely rugged, using materials proven to be effective radiation shields. The makers of the systems design and test the containers to ensure they prevent the release of radioactivity even under the most extreme conditions – earthquakes, tornadoes, hurricanes, floods and sabotage. The containers and their enclosures dissipate heat given off by the used fuel assemblies through natural circulation cooling. The system is passive such that no power source is needed to keep the used fuel cool and safe. The containers are sealed and tested to a high standard of leak tightness to assure that the used fuel assemblies are maintained in a benign inert gas environment. Container internals are engineered with a high degree of precision to assure that an unintended nuclear criticality cannot occur.

Various dry storage container designs typically hold 24 to 87 used fuel assemblies – depending on specific fuel type and container design. To date, more than 1,600 dry casks have been loaded and placed in service at 56 reactor sites in 30 states. Of the approximately 237,000 assemblies that have been discharged from commercial reactors in the U.S. industry's 50-year history, approximately 65,000 have been removed from pools and loaded into dry container systems. The U.S. industry is loading about 6,500 assemblies into 150 containers each year. All of this has been accomplished safely, with no harmful release of radioactivity to the environment. By 2020, over 2,600 of these systems will be loaded at 75 locations in 33 states. [1].

The inherent safety of dry cask storage, as well as the durability of the systems, has been recognized by the Nuclear Regulatory Commission (NRC). NRC's regulations originally called for the dry container storage systems to be licensed for 20 years, with an option for a 20-year renewal. Considering the extensive experience that has been gained since the first dry container systems were put into service, the NRC in 2011 amended its regulations to provide for a 40-year license with an option for a 40-year renewal [2]. In promulgating this extension, the Commission concluded "This increase is consistent with the NRC staff's findings regarding the safety of spent fuel storage as documented in the renewal exemptions issued to the Surry and H.B. Robinson Independent Spent Fuel Storage Installations (ISFSIs)[2]" [2]. Similarly, the Commission's 2010 Waste Confidence update included a generic finding that used fuel generated at any reactor "can be stored safely and without significant environmental impacts for at least 60 years beyond the licensed life for operation." In making this finding, the Commission concluded "studies performed to date have not identified any major issues with long-term use of dry storage" [3]. Given that 70 percent of U.S. reactors are licensed for operation up to 60 years, the NRC has expressed confidence that it is safe to store used nuclear fuel at reactor sites for up to 120 years.

Perhaps the most significant demonstration of the longevity of dry cask storage systems was provided by the Dry Storage Characterization Project completed in August of 2001. This project opened a Castor V/21 cask stored from 1985 to 1999 and verified that "long-term storage has not caused detectable degradation of the spent fuel cladding or the release of gaseous fission products" [4]

Finally, the confidence in the safety of dry cask storage provided by these studies is also shared by the general public. A February 2012 public opinion survey found that 64 percent of Americans believe that storing used nuclear fuel at reactor sites is safe [6].

ADDRESSING FUTURE CHALLENGES – HIGH BURNUP FUEL

As the dry cask storage industry was maturing, and the long-term safety of the used fuel being discharged at the time was being established, a separate trend was developing in reactor operations where fuel was being used in the reactors for longer periods of time. That trend of increasing the discharge burnup of used fuel was enabled by the introduction of improved fuel designs with new, corrosion-resistant cladding materials. In the past few years this HBU fuel has cooled in pools to the point that it is now also being loaded into dry cask storage. Already, approximately 200 casks have been loaded with HBU fuel and almost all used fuel currently

[2] The Surry and Robinson nuclear power plants were the first two dry cask storage facilities (ISFSIs) to receive 40 year license renewals

being discharged from reactors is HBU fuel.

Even though the entrance of HBU fuel into the dry storage marketplace is relatively recent[3], industry and NRC have already begun to proactively re-examine the established technical basis for long term storage. Programs have been developed to examine the aging characteristics of HBU fuels of multiple cladding types to confirm that the conclusions of previous studies can continue to be supported as these fuels begin to conclude their first decade in dry storage. Most of the lower burnup fuel previously discharged has already been loaded into dry storage, meaning most future dry cask loadings will include HBU fuel. (Table I below summarizes the current HBU experience)

Several dry storage facilities at which HBU fuels are stored are now coming due for license renewal (see Table I), meaning the facility operators will need to put in place aging management programs to address questions about whether or not the conclusions already reached for long term storage of low burnup fuel remain valid for HBU fuels.

Table I. Licenses for high burn-up fuel storage to be renewed over next few years

Year Renewal Due	License to be renewed	Type of License
2012[4]	Prairie Island-TN-40, Calvert Cliffs-NUHOMS[5]	Site Specific
2015	Transnuclear-NUHOMS 1004	General
2020	NAC-UMS; Holtec-Hi-STORM	General

In anticipation of the need for confirmatory scientific and technical work to support the aging management plans that would be part of these dry storage license renewals, in 2009 the Electric Power Research Institute (EPRI) organized the Extended Storage Collaboration Program (ESCP) to share information and data related to longer-term storage of used nuclear fuel and transportation following extended storage.

The ESCP is an international partnership between industry, government, and scientific organizations that is conducting work in three stages:

1. Identify technical data gaps that need to be addressed to project the longer-term evolution of dry storage and transportation systems including the used fuel.
2. Conduct smaller-scale cold and hot cell testing, developing models, perform field inspections, and conduct small-scale, longer-term testing.

[3] The majority of HBU fuel in dry storage has been loaded in the past 6 years, with only a small amount having been loaded 7 to 9 years ago
[4] NRC review of renewal application underway
[5] Since 1992, allowable burn-up to 47 GWd/MTU, since 2010, up to 52 GWd/MTU

3. Develop and conduct full-scale confirmatory demonstration project(s)

One of the more significant projects being discussed by ESCP is the High Burnup Dry Cask Storage Demonstration Project. This project which is being led by EPRI, in collaboration with a number of industry partners will be briefly described in the next section of this report.

The commencement of this project is timely as, even though the first license renewals for dry storage systems containing HBU fuel are coming due now (as shown in Table 1), the length of time that HBU has actually been stored in these systems is still relatively short (less than 10 years). Therefore, there is still ample time to collect data on the aging of HBU in storage to validate models and analysis that will predict its longer term performance before any HBU has actually been in storage for periods of time significantly exceeding the original 20 year licensed period of the storage systems. However, it is important that industry begin collecting this data as soon as possible, as some HBU fuel is now nearing the end of its first decade in storage. It will take time to get the High Burnup Dry Cask Storage Demonstration Project underway and to generating data.

NRC has also recognized the importance of the timely collection of data on HBU fuel in dry storage and conveyed its expectations for the inclusion of programs to gather this data in industry aging management plans by conveying the following Request for Additional in its review of the two ongoing dry cask storage license renewal applications:

> "The aging management program should define specific confirmatory inspection or monitoring of stored High Burnup Fuel (HBF) to address conflicting information, uncertainities, or indications of the presence of specific potential aging effects on the fuel. The program may specify inspection and monitoring of HBF within the cask system after 20 years of storage and at periodic intervals (e.g., every 10-20 years) during the renewal period; and may define an alternative, optional program to periodically review and use surrogate confirmatory information from other confirmation programs in the U.S. with similar HBF. The applicant may also consider proposing licensing conditions to limit the scope or storage time of HBF during the renewal period to address uncertainties and lack of confirmatory data." [7]

Given the NRC's expectations, there are obvious advantages to conducting a demonstration project rather than reopening casks at numerous sites to inspect and monitor HBU used fuel.

THE HBU FUEL DRY CASK STORAGE DEMONSTRATION PROJECT

The HBU Fuel (greater than 45 GWD/MTU) Dry Cask Storage Demonstration Project is being designed to gather prototypic data from real HBU used fuel stored in real dry storage systems. This project is intended to provide the "surrogate confirmatory information" being called for by NRC in staff's review of the two ongoing license renewal applications by informing aging management plans. It will also support longer term dry storage license renewals (>60 years) by providing long lead time data and support the transportation of high burn-up fuel to a consolidated storage facility and/or Yucca Mountain or other disposal site by confirming the condition of HBU prior to transportation after a period of storage. Finally, the project is expected to address public confidence in the safe long term management and transportation of HBU fuel by providing tangible evidence of its condition in storage.

This project will be similar to the previously discussed project that opened and examined lower burn-up fuel (less than 35 GWD/MTU) stored in dry casks at Idaho National Lab. However, this project will be instrumented in advance to gather data as soon as the cask is loaded. The data collected over the first few years of the project will be highly valuable in establishing a realistic assessment of the conditions that will govern the subsequent aging of the fuel. After a period in storage the demonstration cask will opened to examine the HBU fuel. The proposed project will consist of the following elements:

- Develop a detailed program plan/design and obtain necessary NRC approvals
- Load well characterized used HBU fuel of multiple cladding types into an existing bolted[6] storage cask at a reactor site
- Using a specially instrumented lid, begin collecting data on temperature, moisture content, and internal gas composition immediately
- Perform hot cell examinations of sample rods, taken from the same HBU fuel but not placed in dry storage, for baseline comparison
- After 10 years or longer in storage, transport the demonstration cask to a fuel transfer and examination facility to perform visual and physical tests in a hot cell

When completed, the project will provide data to address a wide range of technical issues, or data gaps, concerning HBU fuel in long term storage and other aspects of dry storage system aging performance. These issues are summarized in Table II below:

[6] A bolted cask dry storage system is preferable to a welded canister dry storage system because it will be much easier to retrieve the stored fuel for examination with a bolted system.

Table II Data Gaps Addressed by the HBU Fuel Dry Cask Storage Demonstration Project

Dry Storage Parameter	Relevant Data That Could Be Gathered by Demo
Fuel	• Fuel pellet swelling • Rim effects (cracking/bonding) that could lead to particulate or fission product gas release
Cladding	• General and localized corrosion • Delayed Hydride Cracking (DHC) • Embrittlement: Hydride reorientation • Creep: high temperature
Fuel Assembly Hardware	• Metal fatigue caused by temperature fluctuations
Metallic Seals	• Creep • Metal fatigue caused by temperature fluctuations
Bolts	• Atmospheric corrosion • Aqueous corrosion • Mechanical degradation (e.g., creep, fatigue) • Embrittlement • Microbially-influenced corrosion (MIC)

The U.S. industry is committed to pursuing this program, and has already begun work on its initial stages. However, there is also interest in DOE in funding such a project. DOE funding would be appropriate because extended dry storage of HBU fuel is necessary due to the government's unmet statutory and contractual obligation to remove used fuel from reactor sites. DOE also has significant infrastructure and research capability that will be valuable in the later stages of the project. In November 2012, DOE issued a Sources Sought notification to begin the process of government involvement in this type of project. [8]

NEXT STEPS

As mentioned, the initial design work on the HBU Dry Cask Storage Demonstration Project is already under way. In 2013 industry will develop a detailed test plan, a preliminary instrumented lid design, and begin preparing license amendments to NRC for approval for storage. The goal is to load one or two of these specially instrumented casks in 2015 at a U.S. commercial reactor site. At least one capable site with bolted cask dry storage systems and a desirable inventory of HBU used fuel have been identified – Dominion's North Anna plant – and a second cask at Xcel Energy's Prairie Island Plant may also be added.

Of course the aging of HBU fuel is not the only consideration in the long term management of used fuel. A comprehensive program to acquire confirmatory data and inform aging management plans must consider all aspects of dry cask storage – not just the fuel in storage in bolted lid systems, but also the canisters and overpacks in which they are stored for welded canister systems. Regarding welded canister systems, the further into the future they are projected to be in use, the more industry believes that emphasis should shift to the stainless steel canisters (rather than the cladding) as the primary means of assuring safety. In this regard, EPRI has already begun a program of canister inspections. Industry is also committed to assuring that the same level of effort now being put into the HBU Dry Cask Storage Demonstration is carried over into all elements of such a comprehensive program. Given recent decisions by the U.S. Department of Energy that effectively postponed much further the already overdue removal of used fuel from reactor sites, industry expects that a comprehensive program to confirm the longevity of dry cask storage will also be a major mission focus for the federal government.

CONCLUSION

Throughout the 50 year history of commercial nuclear energy production, the U.S. nuclear industry has been highly adept at adapting to changing conditions. One area in which such adaptation has been most necessary has been in response to the uncertainties of the nation's federal used fuel management program, which began with an emphasis on reprocessing, then promised a geologic repository by 1998, then delayed the repository several times, and now is stalled for an indeterminate period of time. Dry cask storage, deployed in response to these changes in the federal program, has been one of the industry's most innovate and successful adaptation mechanisms. Industry is now building on this success, and again proactively working on innovative solutions to assure that dry cask storage can continue to be relied on well into the future. The HBU Dry Cask Storage Demonstration Project is the latest innovative step in this adaptation process.

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