Operational Challenges of Extended Dry Storage of Spent Nuclear Fuel – 12550

M. Nichol
Nuclear Energy Institute, Washington DC

ABSTRACT

As a result of the termination of the Yucca Mountain used fuel repository program and a continuing climate of uncertainty in the national policy for nuclear fuel disposition, the likelihood has increased that extended storage, defined as more than 60 years, and subsequent transportation of used nuclear fuel after periods of extended storage may become necessary. Whether at the nation's 104 nuclear energy facilities, or at one or more consolidated interim storage facilities, the operational challenges of extended storage and transportation will depend upon the future US policy for Used Fuel Management and the future Regulatory Framework for EST, both of which should be developed with consideration of their operational impacts.

INTRODUCTION

In the past, when there was a defined path to developing a repository for final disposal of used fuel, there was little if any anticipated need for extended dry cask storage, defined as more than 60 years, and subsequent transportation. However, the potential need for dry storage beyond 60 years has become increasingly evident since 2010, when the Department of Energy (DOE) withdrew their application for a construction license for Yucca Mountain. Lack of a national repository program, together with the history and current state of US policy for used fuel management, has created significant doubt that a repository will be available in a timely manner, and therefore dry cask storage may be needed beyond 60 years. This is significant since the current regulatory framework was established without anticipating a potential need for dry storage beyond 60 years.

The Department of Energy (DOE), Nuclear Regulatory Commission (NRC), and the nuclear industry have all identified the potential need for extended dry cask storage and transportation (EST). The DOE, NRC, and Electric Power Research Institute (EPRI) have all recently published or will soon publish reports identifying R&D needs to address gaps in data related extended dry cask storage and transportation.[1] The purpose of the R&D is to provide well founded technical bases for safe and secure dry storage beyond 60 years, as well as identify the period beyond 60 years for which the data is valid. To coordinate the various research and development programs, EPRI has formed the Extended Storage Collaboration Project (ESCP), an international collaboration involving the NRC, DOE, US nuclear industry, and international nuclear agencies and companies.

Operational challenges will depend upon the future US policy for used fuel management and the future regulatory framework for EST, both of which should be developed with consideration of their operational impacts. Industry supports an integrated used fuel management strategy that consists of centralized interim storage, research and development of advanced fuel and recycle technologies, and the development of a permanent disposal facility. Improvements to the US policy for used fuel management are necessary to address these considerations, the forthcoming recommendations from the Blue Ribbon Commission on America's Nuclear Future (BRC), and the creation of a potential need for extended dry cask storage and transportation. The current NRC regulatory framework has been developed to address dry cask storage up to 60 years, with an initial license up to 40 years and a 20 year renewal. Regulatory requirements for periods beyond 60 years may differ slightly from those for the first 60 years due to consideration of additional degradation mechanisms and risk informed performance based enhancements.

UNITED STATES USED FUEL MANAGEMENT POLICY

The US used fuel management policy is in a state of flux. The termination of the development of the Yucca Mountain repository program for final disposal of used fuel effectively brought to a close the process laid out in the Nuclear Waste Policy Act of 1982, as amended in 1987 (NWPA). In place of the Yucca Mountain project, the Administration established the Blue Ribbon Commission on America's Nuclear Future with the mission to recommend a new policy for used fuel management in the US. While the future paradigm of used fuel management will depend on the extent to which the BRC recommendations can be implemented, there is unanimous consent that a repository for final disposal is necessary for all scenarios.

There are two important factors of the future US policy that will have an impact on extended storage and transportation operations. The first is the creation of the need for EST through policy decisions. The second is creating requirements for storage and transportation due to policy decisions on the downstream activities related to the repository, and potential consolidated interim storage and/or recycling.

DOE's responsibility for extended dry cask storage and transportation

There would not be a need for EST if the DOE had developed a repository and accepted used fuel in accordance with the 1998 date established in the NWPA and in the Standard Contracts. In addition, prior to the Administration's termination of the Yucca Mountain repository program, there was confidence that a repository would be available well before any cask reached 60 years of dry storage[1]. A repository at Yucca Mountain was expected around 2020, while the first dry storage casks, loaded over 20 years ago, would not reach their 60th year of storage until around 2046.[2]

While the need for extended storage and transportation is not a forgone conclusion, it is an impending reality based upon the current US policy situation and the past experiences with repository selection and development. There is considerable uncertainty that a repository would be available well before 2046, avoiding the need for EST, and considerable lead times to collect the data needed to support storage and transportation licensing beyond 60 years. As a result, industry, DOE and others have taken actions toward research and development for EST.

[1] E.g., NRC Waste Confidence rule updated in 1990 and reviewed in 1999; 10 CFR 51.23, 55FR38474

As DOE is responsible for creating the need for EST, DOE should also be responsible for ensuring the viability of storage and subsequent transportation for as long as necessary and until all used fuel is safely placed in a repository. This includes responsibility for the research and development to produce the technical bases that ensure safe and secure storage and transport beyond 60 years, including those that support development of the regulatory framework and operational capabilities.

It is important to note that DOE still has the legal obligation, as stipulated in the NWPA and agreed to through Standard Contracts, to accept used fuel from utilities and provide for its ultimate disposal. Although the DOE has already breached the January 31, 1998 requirement to begin accepting used fuel, this does not relieve DOE of either its legal obligation to accept all used fuel or its moral obligation to do so as soon as possible.

Impact of the approach for the repository

Fundamental differences in the approach to a future repository, as compared to the approach of the Yucca Mountain repository, will be needed in order to address the differences in the conditions of the 1980s and those expected when a repository becomes operational. While some conditions may have emerged as early as 1998, when the original repository was intended to become operational, the further delay in developing a repository due to termination of Yucca Mountain makes them significantly more influential. In addition, starting over on a repository program from the beginning creates an opportunity to challenge long held approaches in order to better address these evolving and future conditions.

In the mid-1980's, spent fuel pool storage was envisioned to continue to be the primary storage method for used fuel until a repository would be available. Dry cask storage was envisioned to be a unique solution that only a few utilities would need to employ with a relatively limited number of casks. Back then, there were only a handful of casks in-service and it was anticipated that only around 10 plants would require dry cask storage prior to the opening of a repository. Today, in contrast, 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, then there would be significantly more casks in-service.[2] The large difference in the expected number of loaded dry storage casks has a significant impact on decisions related to the repository design and operation.

A future repository will need to accommodate direct disposal of the existing and future casks that will be in service at nuclear facilities, in contrast to the approach for Yucca Mountain to design disposal packages around the repository[3]. The large number of casks in-service challenges the notion that the disposal casks will need to be designed around the repository specifications. Under the old paradigm, such an approach would have been justified considering that most used fuel would be loaded directly from pools into transport casks, then shipped to an above-ground facility to load into disposal packages. Use of a fleet of transport

[2] Dry cask storage amounts extrapolated from Reference 3

[3] E.g., The DOE Transportation Aging and Disposal (TAD) program, although unsuccessful, recognized the benefits of direct disposal of the storage casks.

casks that are loaded directly from spent fuel pools would have been consistent from an ALARA perspective and efficient from a Total System Life Cycle Cost (TSLCC) perspective. However, in a future paradigm, with well over 5,000 casks expected to be in-service when the repository becomes operational, use of specially designed disposal packages would require tens of thousands of additional fuel assembly handing activities resulting in significant worker dose and increased handling risks. Further, such an approach would result in over 5,000 casks ending up as low-level waste. It is foreseeable that a lower risk and less expensive approach, from an ALARA and TSLCC perspectives, would result in transport and direct disposal of existing and future dual purpose storage and transportation casks (DPCs).

For a future repository designed around direct disposal of the existing DPCs, it would be more appropriate for retrievability to be required only for the DPC and not for the individual assemblies. In a future paradigm based upon direct disposal of the storage cask, individual fuel assemblies will not be handled during the process of shipping used fuel to their final placement in the repository. While the storage cask might be required to utilize a disposal overpack, or some other type of additional packaging, the storage cask itself would not need to be reopened to retrieve individual fuel assemblies. Elimination of the need to retrieve individual assemblies would also reduce operational impacts for the upstream dry cask storage and transportation activities.

Impact of consolidated interim storage and recycling

Current and projected used fuel storage conditions at nuclear power plants, and the lack of a repository program, will increase the need for dry cask storage. There could also be many shutdown sites by the time a repository becomes operational[4]. These factors will increase the need for Consolidated Interim Storage (CIS), which provides economies of scale, and a CIS could be an important component to optimize the used fuel "supply chain" from reactors to a repository. It is not anticipated that there would be any significant differences in the operational challenges of EST at a CIS, as compared to EST at a reactor site. However, implementing aging management for EST at a CIS may provide further benefits in economies of scale. There may also be benefits associated with relocation of casks to a CIS, if the CIS location could preclude the potential for a degradation mechanism (e.g. a cask relocated from a plant near the ocean to a CIS located away from the ocean would no longer need to consider the potential for marine atmosphere stress corrosion cracking).

The need for recycling used fuel will be determined by consideration of many factors, including the comparative cost of recycled fuel to freshly mined fuel, non-proliferation, and optimization of the fuel cycle. If retrievability of an intact fuel assembly became a requirement for recycling, it is widely recognized that not all used fuel would be destined for recycling. This is due to both an overabundance of the used fuel resources, and that not all used fuel resources are of sufficient value to undergo recycling. Recycling would also be able to select from an adequate supply of future used fuel discharges, and is not dependent upon used fuel inventories currently in dry storage casks. In this case, retrievability of individual fuel assemblies could be an optional condition that may need to be demonstrated as a condition for recycling. The population of fuel

[4] Plant Life Extension (beyond 60 years) may minimize this impact

assemblies for which retrievability was not demonstrated would still be suitable for a repository via direct disposal of the storage cask, even if they were not suitable for recycling.

REGULATORY FRAMEWORK

In February 2009, the NRC began an initiative to review the existing regulatory framework to evaluate its adequacy to ensure the safe and secure storage and transportation of used fuel for periods beyond 120 years (referred to as Extended Storage and Transportation, or EST). This includes identifying risk informed performance based enhancements to the regulatory framework. This effort is currently on-going and it is too early to know what potential enhancements will be identified. The NRC staff's plans identified that additional research into the aging mechanisms related to cask storage and transportation is important to fulfill the goal of identifying potential regulatory enhancements. Specifically, the NRC identified four phases for the EST program 1) regulatory gap assessment, 2) additional research and analyses, 3) develop and/or extend guidance and regulatory bases, and 4) implement potential rule changes.[4 through 6]

The NRC has also begun a long-term extension to the Waste Confidence rule for more than 60 years after the licensed life of plant operation. As part of the Waste Confidence rule extension, NRC will perform an environmental impact statement (EIS) in accordance with the National Environmental Policy Act (NEPA). The NRC references the termination of Yucca Mountain as the national context, and plans to evaluate extended storage and transportation out to approximately the year 2250. A major assumption in the EIS is that dry cask storage will be the primary mode of storing used fuel over extended periods.[13]

The existing regulatory framework is based upon the following primary safety functions for both storage and transportation casks[5]: 1) prevention of criticality, 2) confinement/containment of radioactive material, 3) shielding from radiation, and 4) thermal performance. While the cask is the primary barrier to prevent release of radioactive material, the fuel cladding is also credited to ensure safety functions of the cask system. For example, storage casks also have a requirement for retrievability and prevention or containment of gross cladding rupture, while transportation casks have a requirement to prevent substantial alteration of the geometric configuration under normal conditions.[7 through 9]

Material properties and performance are important factors in demonstrating that the cask systems perform their safety functions. As such, the potential for material degradation is the main concern as the cask system ages, and is the primary focus of aging management programs even within the first 60 years of storage.[10] It follows that aging management programs to prevent or mitigate potential material degradation is a primary focus for extended storage beyond 60 years.

Risk informed performance based approaches to ensuring the safety of storage and transportation cask systems will likely identify potential enhancement to the regulatory

[5] Dry Cask Storage is regulated by 10 CFR Part 72, and Dry Cask Transportation is regulated by 10 CFR Part 71

framework that would make it more efficient and effective. Several studies useful for developing risk insights already exist, however, these typically do not address the effects of extended storage and transportation. Additional more focused studies should be beneficial in identifying potential enhancements.

Cask integrity should be primary focus to ensuring safety

In the existing regulatory framework for storage and transport within 60 years, the cask is the primary focus for ensuring confinement/containment and providing shielding from radiation. In contrast, cladding integrity provides defense-in-depth for confinement/containment, and is not a significant component in shielding. While the current regulatory framework credits geometry control, provided by cladding integrity, for preventing criticality, it is not the only means by which this safety function could be performed. Another method would be crediting the cask's confinement/containment boundary for precluding intrusion of moderator. Cladding integrity might also not be an important factor for ensuring thermal performance during EST, since the heat generation of used fuel aged for over 60 years would not be significant.

Requiring cladding integrity for extended storage and transportation would likely not provide much additional safety benefit for EST[6]. Current data is insufficient to identify which assemblies may be potentially susceptible to loss of cladding integrity, but even if the potentially affected assemblies could be identified, the risks of the mitigation techniques may exceed the benefits. For example, mitigation of the potential loss of cladding integrity would likely require opening the cask and handling the fuel assembly in order to place the affected fuel into cans. This would result in significant worker dose and fuel handling risks. However, the safety benefits of mitigating potential loss of cladding integrity may be relatively minor since the cask provides the primary safety functions.

In addition, the R&D necessary to characterize the potential for loss of cladding integrity is substantial. Furthermore, it is not readily evident that, even if such data becomes available, it would be possible to utilize the data to identify actual assemblies that are potentially susceptible to loss of cladding integrity. Given the substantial effort and cost required to acquire the data, and the uncertainty in the value of the data, it would be more effective to focus R&D on addressing mitigation of potential degradation of cask integrity. This could further support the risk based safety argument that it would not be appropriate to ensure cladding integrity or assembly retrievability.

It is not necessary to ensure retrievability of individual used fuel assemblies in order to ensure overall safety. The requirement for retrievability during storage is predicated more on the consideration of future reprocessing or disposal activities (e.g. presumption that future

[6] Loss of cladding integrity becomes a concern for EST because there are certain degradation mechanisms that only occur as the fuel cools sufficiently.[11] As the fuel ages, the cladding cools and, especially for high burn-up fuel, the cladding becomes more brittle (due to hydride reorientation) and thus more susceptible to potential failure. Primarily cladding integrity is of concern for transportation and more specifically for transportation accidents. Cladding integrity during storage is not a significant concern since the loads experienced during storage are not typically sufficient to challenge the integrity of even extremely brittle cladding. The inert atmosphere is an important factor that inhibits potential degradation mechanisms from challenging cladding integrity.

reprocessing or disposal will require handling individual fuel assemblies)[7], but is not itself essential to ensuring safety during storage, transporation, disposal or recycling. Retrievability of the fuel assembly is important when opening a storage cask, but it is not the only means available to ensure safe handling. The risk being mitigated by ensuring retrievability of a fuel assembly may be insignificant, since there may be little if any need to directly handle the used fuel inside dual purpose storage and transportation casks[8] since direct disposal of a canister is for a future repository. Even if fuel inside the cask needed to be handled, other means to ensure safety, such as design features and operational procedures to protect workers from unnecessary dose at the facility where the cask is opened may be more effective at reducing overall risk.

From an aging management and operational perspective, ensuring integrity of the cask is more appropriate than ensuring integrity of the cladding. Aging management, which relies upon inspection and mitigation, could be performed relatively easily on the outer cask, but there would be significant challenges to inspecting, mitigating or repairing potential degradation to fuel assemblies or internal cask components.[11,12] The cask is much more accessible for inspection, mitigation and repair, when compared to the assemblies and cask internals which are sealed inside of the casks. For example, an extreme case of mitigating potential damage to the cask might be to place it inside of an overpack capable of providing redundant confinement/containment. This would be operationally easier, and have less risk, than mitigation of potential cladding damage, which would likely require opening the storage cask, thereby disrupting the protection provided by the inert atmosphere, and placing the fuel inside a can. Considering the impacts of aging management activities between the two approaches might further support the conclusion that there would be significantly less overall risk if ensuring cask integrity is the primary focus and there are not requirements for assembly retrievability or cladding integrity.

It is important to determine, from an overall risk perspective, the level of confidence that cladding integrity provides to ensuring the safety functions of confinement/containment are achieved. In this respect, it is important to develop Probabilistic Risk Assessments (PRAs) that examine the overall risks when cladding integrity is maintained and when cladding integrity is not maintained. This will lead to an understanding of the overall risk reduction achieved by maintaining cladding integrity, which should be considered in the context of the risks of the associated mitigation methods. These results could demonstrate that providing assurance that cladding will remain intact during transportation is not a necessary requirement, and may not be the most effective means to ensure safety and minimize overall risk.

Effects of extended storage and transportation on current storage

Risk studies combined with on-going research and development on the technical aspects of extended storage and transportation may very well result in changes to the regulatory framework for EST. Such changes should be implemented in a phased approach to the regulatory framework for extended storage and transportation. In a phased approach, any

[7] 10 CFR Part 72.122(l)

[8] Casks that are only licensed for storage would need to be licensed for transport in the future

requirements unique to extended storage and transportation would not apply until the casks have aged to the point where the safety concern(s) exists. This would prevent the need to perform unnecessary aging management and mitigation before the potential degradation mechanism is postulated to occur.[9] Such a balanced approach would ensure efficient use of industry and NRC resources and ensure regulatory effectiveness. A phased approach would not preclude the adoption of regulatory framework enhancements, through the use of risk insights, for storage within the first 60 years, provided these would also lead to near term improvements in efficiency and effectiveness.

CONCLUSIONS

Risk insights into the regulatory framework may conclude that dry storage and transportation operations should focus primarily on ensuring canister integrity. Assurance of cladding integrity may not be beneficial from an overall risk perspective. If assurance of canister integrity becomes more important, then mitigation techniques for potential canister degradation mechanisms will be the primary source of operational focus. If cladding integrity remains as an important focus, then operational challenges to assure it would require much more effort.

Fundamental shifts in the approach to design a repository and optimize the back-end of the fuel cycle will need to occur in order to address the realities of the changes that have taken place over the last 30 years. Direct disposal of existing dual purpose storage and transportation casks will be essential to optimizing the back end of the fuel cycle. The federal used fuel management should focus on siting and designing a repository that meets this objective along with the development of CIS, and possibly recycling. An integrated approach to developing US policy and the regulatory framework must consider the potential operational challenges that they would create. Therefore, it should be integral to these efforts to redefine retrievability to apply to the dual purpose cask, and not to apply to individual assemblies.

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[9] Not all storage casks will be used for more than 60 years. It would be burdensome to enforce EST requirements on casks that would never be used beyond 60 years.

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