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Licensing Strategies for the Future Transportation of High Burn Up Spent Nuclear Fuel

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ABSTRACT

The current uncertainty surrounding the licensing and eventual opening of a long term geologic repository for the nation's civilian and defense spent nuclear fuel (SNF) and high level radioactive waste (HLW) has shifted the window for the length of time spent fuel could be stored to periods of time significantly longer than the current licensing period of 40 years for dry storage. An alternative approach may be needed to the licensing of high-burnup fuel for storage and transportation based on the assumption that spent fuel cladding may not always remain intact. The approach would permit spent fuel to be retrieved on a canister basis and could lessen the need for repackaging of spent fuel. This approach is being presented as a possible engineering solution to address the uncertainties and lack of data availability for cladding properties for high burnup fuel and extended storage time frames. The proposed approach does not involve relaxing current safety standards for criticality safety, containment, or permissible external dose rates.

INTRODUCTION

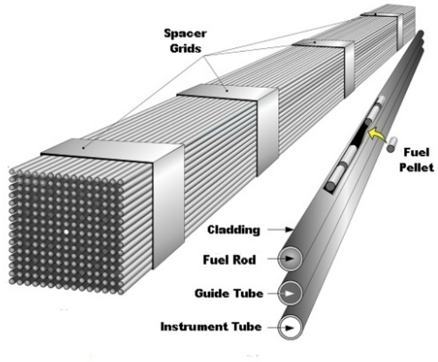
Traditionally, there have been two basic philosophical approaches applied to dry storage of spent nuclear fuel (SNF) in canisters. The first is to prepare and package the fuel in a manner that demonstrates that the canister and spent fuel cladding will continue to satisfy safety requirements for the entire duration of the storage period. This approach requires that neither the canister nor the fuel cladding would degrade beyond a specified design limit, and assumes that sufficient data is available to assure that such degradation can be prevented. Weaknesses in this approach include: (1) the lack of reliable data for fuel cladding subjected to high burn-ups or long storage periods, or the need to extrapolate licensing parameters from limited existing data points, and (2) the overall inability to reliably monitor fuel cladding condition during storage. Since there is essentially no way of refurbishing or repairing damaged cladding, this approach may ultimately lead to the need for repackaging of fuel assemblies, especially if subsequent data is obtained that contradicts current licensing assumptions, or future regulators are unwilling to accept questionable extrapolations.

The second traditional approach is to assume that canister and/or fuel cladding degradation will occur, and to plan for remediation and/or periodic repackaging when deemed necessary. Again, a shortcoming to this licensing approach is the inability to actually monitor the condition of fuel cladding at any particular time to determine if or when repackaging is actually needed. In addition, this licensing method would require that every package be unloaded and its contents repackaged into an additional canister, increasing dose, cost, and the probability of a handling accident.

By contrast, if the spent fuel inner canister itself is considered to be the waste form, a licensing approach that could alleviate the regulatory need for repackaging, provide an added degree of defense in depth, and increase public confidence in interim storage by assuring that the canisters are suitable for long term storage and safe transport could be envisioned.

DISCUSSION

Storage and transportation casks and packages provide three primary safety functions – containment, to prevent release of radioactive material to the environment; shielding, to limit external radiation doses; fuel geometry control, to assure that cask contents remain sub-critical. In addition, SNF must remain retrievable in order to facilitate its use in subsequent operations, or to respond to unexpected circumstances [1]. Containment, shielding and geometry control are achieved, for most designs, through the use of three primary safety barriers – fuel cladding, an inner canister, and either a storage or transportation overpack (See Figure 1). Under the current licensing paradigm for SNF storage casks, fuel cladding has been used primarily to assure a sub-critical geometry, and to provide a secondary containment boundary for gaseous fission products. The inner canister, usually fabricated of stainless steel, has been used to assure containment, and the outer storage overpack used to provide shielding. The storage overpack generally does not provide containment because it is often designed with vents to support the passive cooling of the canistered SNF.



Fuel Assembly

Spent Fuel Canister

Storage Overpack

Figure 1: Elements of Spent Fuel Storage Systems

The current licensing paradigm for transportation casks also depends on fuel cladding to assure a sub-critical geometry. Containment and shielding are both provided by the transportation overpack (Figure 2). The transportation overpack is designed with leak-testable seals, typically elastomeric or metallic, to assure containment and the overpack typically consists of lead or depleted uranium shielding sandwiched between steel shells. Thus, the current licensing paradigm for both storage and transportation relies on assuring that SNF cladding remains largely intact to maintain a sub-critical geometry. The shortcoming for this approach is that SNF would need to be repackaged if degradation of fuel cladding occurs or cannot be ruled out.

Figure 2: Rail Transportation Overpack

With this in mind, SNF packaging strategies for extended storage and subsequent transportation should consider designs that move the safety functions traditionally performed by the fuel cladding to the canister or other components of the packaging. If the fuel is not relied upon to perform the necessary safety functions such as geometry control, degradation of fuel cladding may not pose a significant problem. For example, if a canister is credited for maintaining confinement in storage, a breach of fuel cladding may have little or no safety consequence. Similarly, canister design features such as baskets, poisons, and/or exclusion of moderator can provide criticality safety with little or no reliance on the condition of the fuel cladding. A demonstration that a critically safe geometry can be maintained, regardless of the loss or degradation of fuel cladding, is also possible [2]. Even the operating and safety considerations associated with retrievability can be achieved at the canister level. Thus, the future need for repackaging may be eliminated, or at least reduced, by relying on a canister centered approach to criticality safety, rather than relying on maintaining the integrity of fuel cladding for higher burn-up fuels.

A comparison of the relevant roles of the three primary safety barriers (fuel cladding, inner canister, and overpack) is shown in Table 1 for both the current and proposed canister-based paradigm.

Table 1
Roles of Barriers in Meeting Safety Criteria for Storage and Transportation

CURRENT PARADIGM			
Operation	**Criticality Safety**	**Containment**	**Shielding**
Storage	Cladding	Canister	Overpack
Transportation	Cladding	Overpack	Overpack
CANISTER-BASED PARADIGM			
Operation	**Criticality Safety**	**Containment**	**Shielding**
Storage	Canister	Canister	Overpack
Transportation	Canister	Overpack	Overpack

The proposed reliance on a canister-based approach would not result in any physical changes to the actual condition of the fuel cladding. The conditions (e.g., fuel rod pressure, drying temperature, dryness, etc.) that govern potential cladding failure mechanisms and future retrievabilty are established during initial drying and loading operations. Since the initial loading and drying operations would be the same for the canister based approach, the expected behavior of the fuel cladding would be expected to be identical to that anticipated using the current paradigm for storage and transportation based on assuring cladding remains intact.

An additional advantage of the canister based approach is that the condition of the inner canister is easier to monitor than fuel cladding. This concept is illustrated in Tables 1 and 2 for storage and transportation.

Table 2
Ability to Monitor the Performance of Barriers in Meeting Safety Criteria for Storage

	CLADDING	CANISTER	OVERPACK
Ability to Monitor or Confirm	Visual confirmation would likely require canister opening, or penetrations, Could be based on extrapolation from limited data points	Visual inspections possible Physical testing possible, (e.g., ultrasonic testing)	Visual inspections
Ability to Mitigate	Repackaging	Canister could be patched, coated or overpacked	Overpack could be patched Canister could be moved to new overpack

Since the integrity of the canister can be monitored much more easily than the fuel, failures are easily detected and remediated. For example, a canister could be removed and patched or coated to repair damaged areas and/or placed into a new overpack. In contrast, once a fuel assembly is loaded into a canister and placed in a storage overpack, there is little opportunity to monitor its condition or take mitigating measures if cladding degradation is suspected.

Since the integrity of the canister can be monitored much more easily than the fuel, failures are more easily detected and remediated. Consequently, the technology development needed to provide a technical basis for long-term storage, transportation, and disposal is likely to be much less onerous. Research on cladding properties and fuel structural material becomes less critical; however, it should be noted that due to increased reliance on integrity of canisters/casks and overpacks, the performance of these components may have to be examined with more analytical vigor.

Table 3
Ability to Monitor the Performance of Barriers in meeting Safety Criteria for Transportation

	CLADDING	CANISTER	OVERPACK
Ability to Monitor or Confirm	Visual confirmation would likely require canister opening, or penetrations, Could be based on extrapolation from limited data points	Visual inspections possible Physical testing possible, (e.g., ultrasonic testing)	Visual inspections
Ability to Mitigate	Repackaging	Canister could be patched, coated or overpacked	

A canister based packaging approach does not, in any way, advocate for a reduction in the effort to preserve the integrity of the fuel cladding. The physical condition of the fuel is expected to be identical to what it would be when licensed under the current paradigm. It does, however, assure that safety functions will continue to be performed even if fuel cladding becomes compromised – thus assuring that any unforeseen damage to the fuel or cladding would not jeopardize the basis for safe storage and transportation or unacceptably limit future disposition paths. The primary difference between these approaches is that the current licensing basis for casks is cladding integrity, while the licensing basis for the canister based approach is canister integrity. The same safety functions are achieved by either approach, but the canister based approach assures the public that fuel in interim storage has a high probability that it can be transported safely.

It should be pointed out that the center of the canister-based SNF packaging strategy is to move the safety functions of the package from reliance on the fuel cladding integrity to the canister. In order to do so, the designer must take into considerations of the impact of fuel reconfiguration to the criticality, shielding, and thermal functions of the cask under normal operation and storage because the cladding integrity is no longer assumed, nor evaluated. A bounding fuel reconfiguration scenario should be evaluated separately for all three of these safety functions for which the integrity of the fuel would otherwise be assumed. These bounding reconfigured scenarios should be structured in such a way that they are not dependent on maintaining a specific fuel geometry, therefore making monitoring of the canister internals not necessary.

While the canister-based approach may require an applicant to complete a more extensive set of technical analyses for certification of a storage or transportation system, it is not expected to require a significant change in the regulations.

Finally, it should be recognized that any packaging strategy must be compatible with the ultimate use or disposal of SNF after storage. However, since the physical condition of the fuel using a canister based approach is expected to be identical to that licensed under the current paradigm, it is not anticipated that this would be a major impediment to use of a canister based approach.

CONCLUSION

Packaging strategies and regulations should be developed to reduce the potential for requiring fuel to be repackaged unnecessarily. This would lessen the chance of accidents and mishaps during loading and unloading of casks, and decrease dose to workers.

A packaging approach that shifts the safety basis from reliance upon the fuel condition to reliance upon an inner canister could eliminate or lessen the need for repackaging. In addition, the condition of canisters can be more readily monitored and inspected than the condition of fuel cladding. Canisters can also be repaired and/or replaced when deemed necessary. In contrast, once a fuel assembly is loaded into a canister and placed in a storage overpack, there is little opportunity to monitor its condition or take mitigating measures if cladding degradation is suspected or proven to occur.

REFERENCES

1. Title 10, *Code of Federal Regulations*, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste," Section 122 (l), U.S. Nuclear Regulatory Commission, Washington, D.C. January 2012.
2. NUREG-6835, Effects of Fuel Failure on Criticality Safety and Radiation Dose for Spent Fuel Casks, U.S. Regulatory Commission, September 2003.