Critical Issues Affecting Direct Disposal of Dual Purpose Canisters

Purpose

This report recommends issues for which further investigation will contribute to evaluation of direct disposal of commercial spent nuclear fuel (SNF) in existing dual-purpose canisters (DPCs). It includes a sort based on team consensus as to which issues are most important and amenable to resolution using the resources of the Used Fuel Disposition (UFD) campaign.

Introduction

The total U.S. inventory of SNF is more than 65,000 metric tons (MT) of heavy metal, with approximately 25% of this amount in dry storage casks at reactor sites. These casks currently contain up to 32 pressurized water reactor (PWR) or 68 boiling water reactor (BWR) fuel assemblies. Cost, schedule, and radiation exposure considerations are leading utilities to consider future system designs with higher (37 PWR and 89 BWR) fuel loadings. Many of these casks are licensed for both storage and transportation of SNF, but none are licensed for disposal.

Higher thermal output of DPCs (compared to smaller, purpose-built disposal packaging) can be reduced using decay storage, although heat output will always be greater than the same SNF in smaller containers. Repackaging into smaller containers would increase the total number of canisters, and increase cost, radiation exposure, and waste generation (e.g., DPC hulls). Both DPCs and alternative containers would require disposal overpacks to provide containment integrity for specified duration, with characteristics selected for performance in particular disposal environments.

This list of issues was compiled from team member input and past issue surveys for the UFD campaign [8]. Various alternative disposal concepts for existing DPCs have been identified [1] and provide context for issue identification. It includes all aspects of feasibility including cost and regulatory challenges, but emphasizes technical issues.

Issues

- Engineering/Technology

  General waste form/waste package considerations:

  1. Condition of SNF and canisters to allow storage and transport up to 50 years after discharge

     The assumption [2] for the feasibility study provides for up to 50 years of decay storage, plus ventilation in an open-mode repository, after discharge from the reactor. An assessment of both the SNF and the canister is needed to provide physical, thermal, isotopic, and other properties to be used for evaluating compliance with appropriate regulations.

  2. The capability to transport the canisters to the repository must be assessed.

Weights for multi-purpose canisters with shipping overpacks range up to 180 tons [6]. This is likely to exceed truck heavy-haul limits (e.g., Ohio permits up to 8 axles: single-tandem-tandem-tridum, limited to a GVW of 174,000 lbs. [7]). Rail transport likely will be required; alternative plans for sites without rail access must be developed. Similarly, for those plants that have been decommissioned, the capability to transfer the canisters into the transportation overpack must be assessed.

3. Consequences of higher heat load from higher loading (up to 37 PWR/ 89 BWR) and higher burnup (up to 60 GWd/MT) fuels

   Proposed SNF packaging for dry storage will result in canisters with heat loadings far higher than those being considered for disposal in existing repositories. The effect of the higher temperature on both engineered and natural materials must be determined.

   The instantaneous power of the package will require analysis to determine the length of decay storage prior to emplacement and ventilation requirements after emplacement of the waste in the repository.

   The energy density affects longer term performance, and will require analysis of the engineered barrier and natural systems to determine suitability of DPCs for disposal.

4. Compatibility of disposal canister materials and waste package materials must be assured, especially in light of disposal environments in different geologic media.

   Near-field physical and chemical conditions will determine waste package materials to be used (disposal overpacks). Interactions of degraded waste package materials, including canister materials, will also influence the disposal environment (consider both oxidizing and reducing conditions).

   Of particular concern are:

   a. In situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the function of the waste packages or the performance of the underground facility or the geologic setting

   b. Solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads, and synergistic interactions are understood and correctly modeled

c. Explosive or pyrophoric materials or chemically reactive materials in amounts that could compromise the ability of the underground facility to meet performance standards are not included or created as the waste packages degrade

Analysis must be performed to establish material requirements for waste packages.

5. Performance of pressurized canister emplacement in repository

After loading, storage canisters are pressurized with helium to reduce cladding corrosion and to provide efficient heat transfer through the canister wall. The emplacement of the pressurized canister in a repository environment must be assessed to ensure the performance is within established limits.

Analysis is required to determine the need for helium, and if, necessary, the duration requirement for containment.

6. Potential for gas generation:

Gases generated following loading of the canister include helium from alpha decay of radioactive isotopes, hydrogen generated from internal corrosion of the canister or fuel, and residual moisture. These must be assessed to determine the effect on pressure and composition of the canister environment.

A trade study can be performed to assess the selection of overpack material selection and design criteria, based on required overpack life, heat output, and moisture content.

7. Shielding of DPCs during transport

Upon receipt of the DPC at the repository site, the canister will be unloaded from the transportation cask. It will require a shielded transfer cask to limit personnel radiation exposure during handling. The size, weight, and materials required for adequate shielding must be estimated to established facility design requirements.

8. Movement of shielded waste package on the surface.

The gross weight of a loaded DPC is currently in the range of 40 to 45 MT. The weight of the Yucca Mountain 21 PWR waste package was approximately 40 to 50 MT. Waste packages for 37 PWR DPCs (e.g., Magnastor) likely would exceed 70 MT. In conjunction with a shielded transfer cask, this could result in a gross weight well in excess of 150 tons. This must be assessed to ensure that that appropriate cranes, hoists, and transport/haulage mechanisms are captured in facility design requirements.

9. Preclosure Safety Assessment for direct disposal of Dual Purpose Containers

   The waste package will have to meet preclosure safety requirements of Nuclear Regulatory Commission regulations, which require a Preclosure Safety Assessment. Event sequences could be influenced by the size and weight of the waste package, particularly if shielded. Events that could impact the direct disposal of Dual Purpose Containers include:

   a. Side impact on waste package
   b. Rock fall from the drift onto the waste package
   c. End of waste package impact
   d. Waste package vertical drops and waste package end collisions
   e. Waste package horizontal drops and waste package side collisions
   f. Drop of waste package by emplacement drift emplacement equipment
   g. Fall onto a sharp object while waste package is being transported in a horizontal position
   h. Tip-over due to vertical drop
   i. Loss of structural integrity due to tip-over during a design basis earthquake
   j. Missile Impact
   k. Transporter runaway due to inability to maintain speed or brake, causing derailment and impact
   l. Fuel rod rupture/internal pressurization
   m. Thermal stresses and peak waste package temperature
   n. Fire in disposal container cell
   o. Criticality scenario inside a waste package

10. Movement of shielded waste package underground

   For movement underground, these weights are well in excess of what historically has been lowered by shaft and may exceed engineering capabilities when Nuclear Regulatory Commission safety requirements are considered. This leads to several issues that require assessment:

   a. Shielding requirement for underground transport or emplacement of waste packages. These may be less than for surface transport, depending on repository design, operation, and specified dose limits for the transport process.
   b. The feasibility of shaft access for waste package emplacement, given the projected weights, for either shielded or unshielded waste packages.
   c. Provisions to be included in the repository design to provide for a safe underground work environment.

11. Stability of underground excavations.

Direct disposal of Dual Purpose Containers may require excavation sizes significantly larger than historically considered for geologic repositories, especially for special features such as intersections, transfer stations, etc. Media-specific excavation designs must address excavation stability and support requirements for such openings, and the possible influence of thermal loading, to demonstrate that openings can be maintained for a ventilation period on the order of 100 years.

Analysis will be performed to provide characterization of host rock.

12. Host rock ground support maintenance

    Ventilation and waste retrieval requirements lead to an expectation that the capability to provide for ground support maintenance must be addressed in the facility design, even if such maintenance is an unanticipated condition.

13. Buffer/backfill performance

    The buffer and backfill materials are part of the engineered system that affects the overall performance of the system. The response of these materials to heat, chemical, and water intrusion will affect radionuclide migration and the overall ability of the system to meet regulatory requirements.

    Analysis will be required to need for backfill permeability, and the effect of heat in the presence of moisture.

14. Features, events and processes (FEPs) that could be influenced by the size and thermal characteristics associated with direct disposal of DPCs need to be identified. FEP analysis consists of identification, screening, and performance assessment modeling. It is an iterative process that is dependent on site-specific information, design alternatives, regulations, and performance metrics.

    These features, events and processes will site have site specific issues such as media-specific issues. Examples include site geology, chemical environment, degree of saturation, permeability, and stability of the host rock. FEPs previously developed for disposal systems should be rescreened to identify FEPs that may be relevant to DPC disposal.

15. Criticality safety

    Analysis is required to provide assurance that the repository system design will preclude post-closure criticality, or that the consequence of such an incident will not affect repository performance. The analysis can evaluate benefits from fuel burnup credit and actual canister loading data, and can be used to provide recommendations for future canister loading to increase the safety margin. A review to identify and evaluate basket materials that could be used for increased neutron absorption to provide a larger margin of safety can be completed.

An assessment can also be performed to evaluate the criticality and radionuclide containment benefits provided by backfilling of future canisters with a liquid/metal mixture that solidifies in the internal void spaces.

- Regulatory

The framework for regulation of SNF repositories lies with the Environmental Protection Agency and the Nuclear Regulatory Commission. Standards for sites other than Yucca Mountain (unsaturated tuft) are defined in 40 CFR part 191, "Environmental Radiation Protection Standards for Management & Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes," and 10 CFR part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories." Yucca Mountain-specific regulations were provided separately, in 40 CFR part197, "Public Health & Environmental Radiation Protection Standards for Yucca Mountain, Nevada," and 10 CFR part 63, "Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada."

The Environmental Protection Agency made significant changes to the regulatory basis of 40 CFR part 191 when it promulgated 40 CFR part 197. Similarly, the Nuclear Regulatory Commission made fundamental changes to the regulatory approach of 10 CFR part 60 when it promulgated 10 CFR part 63, which was required by law to be consistent with the Environmental Protection Agency standards. The Environmental Protection Agency has publicly stated that it will promulgate new standards if Congress directs a new repository program [4]. The U.S. Nuclear Regulatory Commission regulation has moved from one of addressing uncertainty by ensuring that individual components provided certain degrees of performance, to a risk-informed, probability-based assessment of the performance of the system as a whole. Scientists have recognized for years that the subsystem-based approach did not provide assurance that the repository would perform as well as it was able to. A risk-informed, probability-based approach, on the other hand, while placing compliance with the regulation on the performance of the system as a whole, allows the applicant to demonstrate exactly which components of the repository contribute to performance. This approach is consistent with that adopted by the Environmental Protection Agency for 40 CFR part 197. The Nuclear Regulatory Commission has noted that this approach would be embodied in future repository regulations [5].

To enable the investigation of total system performance assessment issues related to the direct disposal of Dual Purpose Canisters it is therefore necessary to make certain assumptions about future regulatory requirements that impact direct disposal of Dual Purpose Canisters. An appropriate basis for assessing critical issues related to a regulatory approach affecting direct disposal of Dual Purpose Canisters would thus appear to be to capture the pertinent aspects of the generic regulations tempered by the changes in regulatory approaches embodied in the site specific regulations. Issues that may affect direct disposal of Dual Purpose Canisters include:

- All Dual Purpose Canister[1] disposal alternatives must meet the NRC retrievability requirement. (10 CFR 60.111(b) [effectively unchanged by 10 CFR 63.111(e)].

- All Dual Purpose Canister disposal alternatives must meet the preclosure safety assessment requirements of 10 CFR 60.111 and 10 CFR 60.131 [effectively unchanged by 10 CFR 63.111].

- The performance standard is assumed to be an individual protection standard, applied at the accessible environment boundary, as defined in 40 CFR part 191. It will be assessed through the use of a risk-informed probability-based total system performance assessment, with releases weighted by probability of occurrence, similar to that of 40 CFR part 197 and 10 CFR part 63. Very unlikely events, those with a probability of occurrence of less than 10^{-8}, need not be considered. The Containment and Assurance requirements of 40 CFR part 191 will not apply.

- The performance standard is assumed to be a two part standard similar to that of 40 CFR part 197, except that the period of geologic stability concept will not be used, as it would lead to required calculation times on the order of hundreds of millions of years for some of the media under consideration. The standard is assumed to be 0.15 mSv for the first 10,000 years and 1.0 mSv from 10,000 years to the time of peak dose if it is less than 1,000,000 years. Calculation times greater than 1,000,000 are significantly less meaningful than those for the first 10,000 years

- Features, events and processes are assumed to be treated in the manner proscribed in 40 CFR part 197 and 10 CFR part 63, except that the Yucca Mountain site specific requirements for seismicity, volcanism, and climate are assumed not to apply. Climate change is assumed to be treated with a simple probabilistic model.

References

1. Hardin et.al., *Media-Specific Alternative DPC Disposal Concepts*, (May 28, 2013)
2. Miller, et.al., *Assumptions for Evaluating Feasibility of Direct Geologic Disposal of Existing Dual-Purpose Canisters*, FCRD-UFD-2012-000352 (September 2012)
3. Blue Ribbon Commission on America's Nuclear Future, *Report to the Secretary of Energy* (January 2012)
4. Fourinash, Betsy, Environmental Protection Agency, in response to a question at WM 13 symposium. (Feb. 25, 2013)
5. McCartin, T., United States Nuclear Waste Technical Review Board, Spring Board Meeting. (Transcript from March 7, 2012).
6. United States Nuclear Waste Technical Review Board, *Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel*, (December 2010)
7. http://www.lgiinc.com/ohio_shipping_permits.html

[1] I have not been consistent on this term. We need to pick one and use it

8. Nutt W.M. 2011. *Used Fuel Disposition Campaign Disposal Research and Development Roadmap*. U.S. Department of Energy, Used Fuel Disposition R&D Campaign. FCR&D USED-2011-00065 Rev. 0. March, 2011.