REVISITING DIRECT DISPOSAL OF DUAL-PURPOSE CANISTER SYSTEMS

Matthew W. Kozak[1], Michael J. Apted[2] and Andrew Sowder[3]

1. *INTERA, Inc, 355 Teller St, Suite 220, Lakewood CO 80228 mkozak@intera.com*
2. *INTERA, Inc. 1812 Centre Creek Drive, Suite 300 Austin, TX 78754 mapted@intera.com*
3. *EPRI 1300 West W.T. Harris Boulevard; Charlotte, NC 28262 asowder@epri.com*

As operational dates for many geologic repositories for commercial used nuclear fuel continue to be pushed out further into the future, many countries, including the United States, will see inventories of high capacity dual-purpose canister systems (DPCs) continue to grow. Planning for disposal in these countries must address this reality as part of a holistic approach to an integrated used fuel management system. While repackaging of used fuel in smaller waste packages for disposal is an option, the ability to directly dispose of loaded dual-purpose storage systems would clearly be advantageous to minimize undue radiological exposure to workers and overall management costs. By contrast, if direct disposal of these systems is unacceptable from a long-term safety viewpoint, this will drive disposal systems to include repackaging as a major activity.

As part of a two-decade program on repository postclosure performance assessment, EPRI evaluated the feasibility and consequences of direct DPC disposal with respect to long-term performance of a U.S. repository for commercial used nuclear fuel at Yucca Mountain in Nevada. This paper reviews the general approach taken by EPRI in evaluating the feasibility of direct disposal of DPCs, focusing on future applicability. Overall, EPRI found no fundamental technical show stoppers that would categorically preclude direct disposal of DPCs for the unsaturated, open repository environment design evaluted. Direct diposal of large capacity DPCs can and should be considered and evaluated as part of an optimized, integrated used fuel management strategy.

I. INTRODUCTION

As part of a two-decade program on repository postclosure performance assessment, EPRI evaluated the feasibility and consequences of direct DPC disposal with respect to long-term performance of a U.S. repository for commercial used nuclear fuel at Yucca Mountain in Nevada.

During development of the proposed Yucca Mountain repository, the U.S Department of Energy (DOE) proposed standardized disposal waste packages for the spent fuel and HLW destined for Yucca Mountain. In 2005, DOE announced the evolution of this design-basis into the Transportation, Aging, and Disposal (TAD) canister design as the exclusive disposable canister for emplacement of Commercial Spent Nuclear Fuel (CSNF) in the Yucca Mountain repository. The DOE stated that in addition to TADs, a finite number of dual-purpose canisters (DPCs, licensed for storage and transportation), currently 10 – 25% of nationwide CSNF disposal inventory, would be shipped to Yucca Mountain. Under this plan, DOE would open these DPCs at Yucca Mountain, transfer the CSNF assemblies into TAD canisters for emplacement in the repository, and discard the empty DPCs as low-level radioactive waste (Ref. 1).

This approach would not take advantage of the significant quantity of CSNF already safely packaged in dual-purpose canisters (DPCs) at the commercial reactor sites that may be appropriate for direct disposal within the repository. The introduction of potentially unnecessary fuel handling activities in the process of transferring CSNF from DPCs to TADs imposes additional risk on workers and increased project costs.

Therefore, EPRI evaluated the feasibility and consequences of direct DPC disposal with respect to long-term performance of the repository.

II. ANALYSIS APPROACH

EPRI estimates that U.S. utilities could load as many as 2,155 DPCs at reactor sites through 2020. Adding the 220 canister-based storage-only dry storage systems in service at plant sites the total number of DPCs and other canister based systems containing CSNF at could exceed 2,375 by the year 2020. Transfer of this inventory into a final disposal container would incur significant costs and potentially unnecessary exposures of workers (Ref. 5).

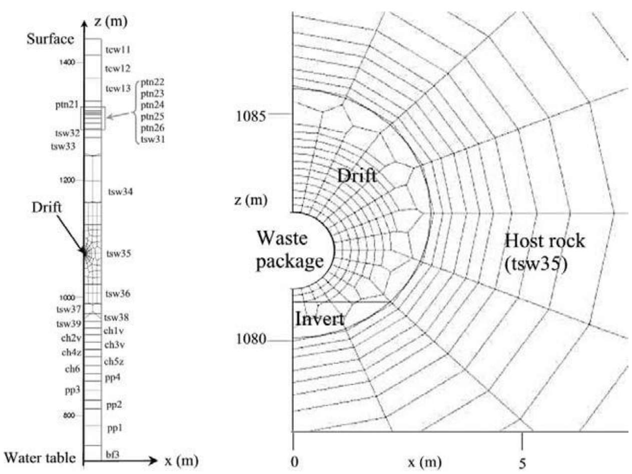
EPRI evaluated the potential for direct disposal of some or all of these containers directly into the repository via three types of analyses: Thermal, Thermo-mechanical, and Total System Performance Assessment (TSPA).

Separate criticality analyses for direct disposal of DPCs (Ref 4, 5) concluded that the likelihood of criticality in a DPC waste package would be comparable to that in a TAD. Moreover, these analyses determined the probability of a criticality event is very low, and falls below the regulatory cut-off for inclusion in TSPA as a FEP. Consequently, criticality is not discussed further in this paper.

II.A. Thermal Analysis

A primary concern for disposal of CSNF is the heating of the engineered barrier system and surrounding rock that could degrade repository performance. Based on previous calculations concerning pillar (the rock between drifts) dry-out, EPRI (Refs. 2,3) compared the calculated performance effects from the direct disposal of DPCs versus TADs.

A two-dimensional model was set up to simulate coupled heat and mass transfer in the Yucca Mountain repository loaded with DPCs. The model was developed using the TOUGH2 code.[1] The model is shown in Fig. 1. For the analysis it is assumed that the entire repository is loaded with DPCs. This assumption is conservative in that it will overestimate the heat loading that would be generated by any real situation involving DPC disposal.



(a) Vertical cross section. (b) Detailed discretization on drift scale.

Fig. 1. Representation of the TOUGH2 model for heat effects from DPC disposal.

Using these boundary conditions and a set of assumed initial conditions for pressure, temperature, and saturation distributions, the model was run without heating from the waste packages, until a steady state was reached. This steady state represents the condition when the liquid flux into the water table is approximately equal to the infiltration rate at the top boundary.

[1] TOUGH2 is a numerical simulator development by Lawrence Berkely National Laboratory.

As an initial step, the model was run for the heat loading associated the TAD waste packages, and model results were compared with DOE analysis results. Comparison of the EPRI and DOE results revealed good agreement (Ref. 2). Details of the inputs for the analysis are presented in Refs. 5 and 6.

In Fig. 2, the temperature histories of the waste package are presented on several locations of the drift wall, and in the drift pillar (the middle plane of the two drifts) for the bounding assumption of 100% of the waste packages as DPCs. The maximum temperature of the waste package is 228 °C, less than the constraint of 250 °C. The maximum drift wall temperatures are 199 °C at the crown, 188 °C at the base, and 202 °C at the side.

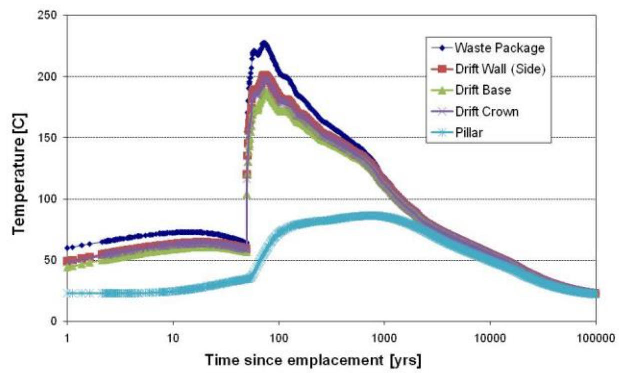


Fig. 2. Temperature effects for the bounding condition of disposal of 100% DPCs in the repository.

The temperatures on the drift wall are close to the 200 °C limit imposed for rock wall temperatures. In spite of this encroachment on the temperature limit, the thermal excursion is not expected to impact host rock performance. First, as shown in Fig. 2, the time period during which the temperature exceeds 200 °C by just 2 °C is less than 10 years. Furthermore, this only happens on the side of the drift, which would be unlikely to cause problems with the host rock surrounding the drift during the early disposal period (< 100 years). Second, this result was generated assuming a 100% DPC inventory for the repository, which, as stated above, is a bounding assumption.

Additional analyses and assumptions are explored in Ref 4, with results consistent with those shown in Fig. 2. Therefore, EPRI concludes that the detailed thermal analyses support the feasibility of direct DPC disposal.

II.B. Thermomechanical Analysis

EPRI (Ref. 7) adopted the same strategy used by DOE of dividing the lithophysal rock mass into 5 strength/moduli categories, Category 1 being the weakest and Category 5 being the strongest. The behavior of a drift in Category 3 (medium) lithophysal tuff subjected to drift wall temperatures up to 200 °C was analyzed using the Fast Lagrangian Analysis of Continua (FLAC) numerical model (Ref. 8). FLAC is a two-dimensional finite difference program for solving a wide range of problems in continuum mechanics. It is a commonly-used and accepted code for problems in rock mechanics.

The analysis reported here is identical to the FLAC analyses reported in Ref. 7 except that higher drift wall temperatures were considered. The analysis was conducted for the bounding heat profile assuming 100% of the waste packages are DPCs.

The results indicate that some yielding is expected to occur around the drifts under the higher drift wall temperatures. For comparison, a yield zone of about 0.6 meters thick is predicted in the Category 3 lithophysal tuff when subjected to drift wall temperatures up to 200 °C, compared with a yield zone about 0.3 meters for the current Yucca Mountain design with maximum drift wall temperatures of about 150 °C. However, the increased yielding is not expected to result in any significant rockfall, because the rock strength within the yielding zone is still 80 to 95% of its initial rock mass strength. Thus stable drifts with isolated rockfall within the first 0.6 meters are predicted.

Smaller, negligible impacts would be calculated for the more likely situation of a combination of DPCs and TADs both present in the repository, as thermal management strategies should lead to peak temperatures below those evaluated in this analysis, and within the design limits for the repository. Therefore, it is concluded that thermal-mechanical factors do not present significant obstacles to direct DPC disposal at Yucca Mountain.

II.C. Total System Performance Assessment (TSPA)

EPRI has been conducting independent assessments of the total system performance of commercial spent nuclear fuel (CSNF) and high level radioactive waste (HLW) repository at Yucca Mountain, Nevada, since 1989. EPRI's total system performance assessment code is formally known as the Integrated Multiple Assumptions and Release Code (IMARC). This analysis of DPC disposal was conducted using IMARC 9 (Ref. 9).

A failure of the drip shields and waste packages can affect the timing and number of waste packages releasing radionuclides from the EBS into the unsaturated zone. Calculations of the rates of corrosion processes affecting the drip shields and waste packages for the 100% DPC repository case were performed using a stand-alone model called EBSCOM (Ref. 4). The EBSCOM code uses Monte Carlo techniques to take into account uncertainty and variability in the prediction of drip shield and waste package lifetimes.

Uncertainty arises from the use of abstracted conceptual corrosion models, which are necessarily simplifications of the actual complex corrosion processes, and from uncertainty in the values of various input parameters. Variability results from variation in, for example, material properties, environmental conditions (both spatial and temporal variation), and the quality of the manufactured waste packages and drip shields. EBSCOM was used as an input to IMARC for the purposes of this analysis, along with updates to the IMARC inputs to represent the thermal and thermomechanical changes to the IMARC 9 baseline analysis for TAD disposal. The results are shown in Fig 3 for the nominal scenario of the TSPA. There is negligible difference in performance between the disposal of waste in TADs vs the disposal in DPCs.

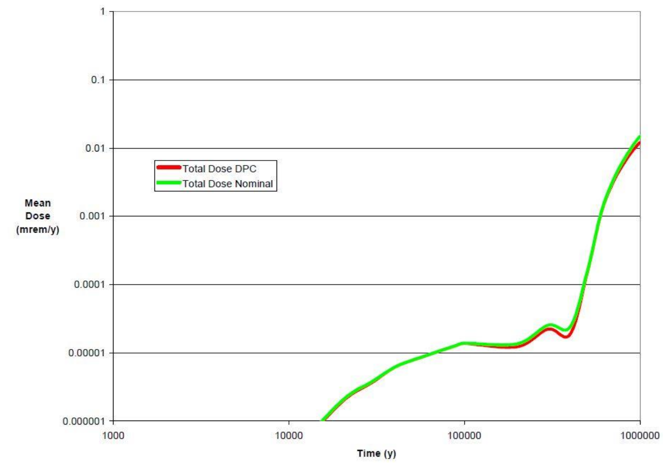


Fig. 3. Comparison of the baseline IMARC 9 results for the nominal scenario with 100% TAD waste packages to the bounding case of 100% DPC disposal.

II.D. Alternative TSPA Scenarios

In addition to the nominal repository evolution scenario, EPRI (Refs. 10-14) conducted analyses related to alternative scenarios for the behavior of the repository. The EPRI analyses of these repository evolution scenarios have been founded on an independent assessment of the geology, volcanic hazard, and seismology at Yucca Mountain. This independent assessment identified a number of conservatisms in the approaches used by DOE in their assessments. EPRI's assessment of DPC disposal is therefore based on EPRI's prior assessments of the alternative repository evolution scenarios rather than DOE's.

EPRI (Refs 10,11,12) evaluated the potential for disruption of the repository performance in the event of an igneous event intersecting the repository. Unlike prior DOE analyses, the EPRI analyses focused strongly on the performance of the waste package in either an eruptive or intrusive igneous event. The waste package disposal overpack forms the primary barrier to releases from the waste package in the igneous scenario. The disposal overpack is the same for either TAD or DPC disposal. Consequently, it is concluded that consequences associated with an igneous event on the repository would be the same for DPC disposal or for TAD disposal.

EPRI (Refs. 13,14) carried out independent assessments of the consequences of seismic events at Yucca Mountain on the post-closure performance of the repository. Among the observations made by EPRI (Refs. 13, 14), it was noted that the prior analyses carried out by DOE contain a number of significant conservatisms, and as a result the EPRI analyses represent a more reasonable estimate of the performance of the repository from a single, large, low probability event (Ref 13), and the performance associated with multiple, smaller events (Ref 14).

EPRI (Ref 14) presented the results of EPRI's evaluations of the potential effects of sequences of multiple seismic events on the total system performance assessment (TSPA) of a repository at Yucca Mountain, and to implement a TSPA for a single sequence of seismic events. The TSPA was carried out for a Base Case analysis and two sensitivity cases, all of which represent the behavior of the repository under a series of events with a 10^5 year return interval, with a peak ground velocity of 0.75 m/s. The EPRI Base Case analysis is closest to a reasonable expectation analysis, though with several key conservative simplifying assumptions, whereas the sensitivity cases include more conservative assumptions. The conclusions of both Ref. 13 and Ref 14. were that seismic effects increase doses at early times associated with early waste package failures, but that the peak dose is not strongly affected by seismic activity.

A DPC waste package is of comparable dimensions and mass to a TAD waste package. Based on these observations, EPRI's prior analyses (Refs. 13, 14) of damage to the Alloy 22 disposal overpack are appropriate when applied to DPC disposal.

Consequently, the only change to a TSPA analysis of the seismic scenario compared to analysis of a 21 PWR waste package is (as in the nominal scenario) an increase in the inventory of an individual waste package and a decrease in the number of waste packages needed. Consequently, it is concluded that the performance response to seismicity of a repository containing DPCs is identical to one containing TADs.

III. APPLICABILITY TO OTHER DISPOSAL CONCEPTS

This paper has examined the potential for direct disposal of DPCs at Yucca Mountain. The NRC recently completed its Safety Evaluation Report of the Yucca Mountain license submission, with generally positive findings (Ref. 15). This development has led to the potential for the project at Yucca Mountain to be revived. However, given the uncertainty about a resurgent Yucca Mountain, it is worth considering whether the approach described here has general applicability to other potential sites and disposal concepts.

The general approach used in this paper is generally applicable to any disposal concepts for CSNF. For any such site and associated design, factors that need to be addressed are thermal effects, thermal-mechanical effects, corrosion, criticality, and potentially other alternative scenarios. The general approaches presented in this paper may therefore be useful in evaluations of DPC disposal in other potential repository conditions. However, the proposed Yucca Mountain repository differed in many regards to other repository designs currently under consideration (e.g. unsaturated conditions). Therefore, it can be concluded that direct extrapolation of our results for Yucca Mountain to the postclosure behavior of other disposal concepts should not be done, but the general approach for evaluation of DPC disposal taken here can be used elsewhere.

IV. CONCLUSIONS

This paper has considered the potential for direct disposal of CSNF in Dual-Purpose Canisters (DPCs) as an alternative to repackaging of such previously loaded CSNF into TAD canisters for disposal. The focus has been on evaluating potential issues associated with DPC disposal in the postclosure period.

Direct DPC disposal was examined to determine if there would be any significant issues relative to thermal effects, thermal-mechanical effects, corrosion, TSPA of the nominal repository evolution scenario and credible alternative repository evolution scenarios, as well as criticality.

It is concluded that there are very small differences in performance of DPCs in the post-closure period compared to performance of TADs. Indeed, there may be no real differences when the degree of conservatism in previous TAD analyses is considered. Criticality is often thought to be an issue for DPC disposal, but is extremely unlikely for both TADs and DPCs. No obstacles have been identified that would preclude the use of DPCs for disposal of commercial spent nuclear fuel (CSNF) in a geologic repository at Yucca Mountain.

Based on these results, consideration of direct disposal of DPCs at other potential repositories should be considered as a means of optimizing disposal concepts considered in the future. Direct extrapolation of our results for Yucca Mountain to the postclosure behavior of other disposal concepts should not be done, but the general approach for evaluation of DPC disposal taken here can be used elsewhere. Direct disposal of DPCs has a number of potential benefits in terms of cost and avoided worker dose that make it an attractive concept.

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