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FACTORS AFFECTING PERFORMANCE OF ENGINEERED BARRIERS*

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INTRODUCTION

For the Yucca Mountain Viability Assessment (VA), a reference design was tentatively selected[1] in September 1997, and a series of model abstractions are being prepared for the performance assessment (PA) of that design. To determine the sensitivity of peak dose rate at the accessible environment to engineered components, several design options were subjected to the PA models available late in FY97.

WORK DESCRIPTION

The base case for the comparative study was the reference waste package (WP) design (2 cm of Alloy 625 nickel-base material inside 10 cm of Alloy 516 carbon steel) placed in a concrete lined drift. It was assumed that radionuclides are released from failed WPs by diffusion only. Outside the WPs, transport through the inverts is assumed to be diffusion limited for 90% of the failed WPs. In the remaining 10%, transport is by advection. Improved corrosion models recommended by the Waste Package Degradation Expert Elicitation (WPDEE) consultant group were used. For the thick corrosion allowance material (CAM), a pitting factor of 1.5 was used, with a standard deviation of 0.25. For the thin corrosion resistant material (CRM), it was assumed that the pit growth rate declines with time and that pitting and crevice corrosion are less sensitive to temperature than assumed[2] in TSPA-95.

Option 1 is a cladding credit case. Based on inventories, 1.15% of the 63,000 MTU of commercial spent nuclear fuel was assumed to be clad in stainless steel. It was conservatively assumed that the stainless steel would not be a substantial barrier. About 0.1% of the zircalloy cladding is expected to arrive perforated, with opening sizes of order tens of microns, caused by creep rupture. Some additional rods were calculated to perforate in the repository due to creep rupture, based on temperature time histories within the WPs. For WPs which fail (and lose their inert gas) while the waste temperature is above 150°C, oxidation and swelling of the UO_2 is assumed to unzip perforated rods. Based on dry storage and spent nuclear fuel pool experience, perforated rods are assumed to have negligible releases if they do not unzip. Spent fuel in unzipped rods is assumed to have surface area increased by 100x.

Option 2 is a backfill case. Credit was taken for reduced relative humidity under the backfill, due to the higher temperatures caused by the backfill's insulation of the Waste Package. To stay within the 350°C cladding temperature limit, the drifts were ventilated at 10 m^3/s for 50 years. Based on a preliminary design analysis (which conservatively ignored latent heat removal), 80% of the heat released was assumed to be removed by the ventilation. A third case combined the cladding and backfill options.

Option 4 is a ceramic coating case. Since ceramics are thermodynamically stable in potential repository conditions and thus do not corrode significantly, the major uncertainty is whether flaws, handling stresses, thermal stresses, and rock falls can compromise the mechanical integrity of the coating and whether there will be slow movement of moisture through its pores. Backfill was assumed to be used to mitigate stresses from potential rock falls, and the ceramic was assumed to fail in a log-uniform distribution between 10,000 and 1,000,000 years. A sub-case had log-uniform failure between 1,000 and 1,000,000 years.

The fifth option improves the CRM. Based on measured short term corrosion rates in extremely aggressive environments, a temperature-dependent Alloy C-22 corrosion rate 100x below the Alloy 625 base case was assumed. A sub-case had a corrosion rate 10x below the base case. Since this sensitivity study was completed, further corrosion data have been analyzed for Alloy C-22, and the WPDEE has provided site-specific corrosion rate estimates. As a result, the VA Reference Design is in the process of being changed to replace Alloy 625 with Alloy C-22.

RESULTS

The base case peak dose rate was 3.5 mrem/yr. The uncertainty in input data and the transitional state of the PA models for the Viability Assessment results in low confidence in this value; however, it is suitable for the purpose of conducting this sensitivity analysis. The results for the base case and sensitivity cases are tabulated in Table 1.

Table 1.

SENSITIVITY CASES ANALYZED		
Case	Peak Dose Rate (mrem/yr)	Reduction from Base Case
Base Case	3.5	–
Cladding Credit	0.08	40
Backfill at 50 yr, with Ventilation	1.0	3.5
Backfill and Cladding Credit	0.025	140
Ceramic Coating Failing between 10^4 and 10^6 yr	0.09	40
Ceramic Coating Failing between 10^3 and 10^6 yr	0.6	6
CRM with 100x Slower Corrosion Rate	0.0	∞
CRM with 10x Slower Corrosion Rate	0.03	100

Cladding credit resulted in a peak dose rate of 0.08 mrem/yr, about 40x lower than the base case. This improvement is expected since less than 2% of the waste form is available for degradation and mobilization using these assumptions.

Backfill resulted in a peak dose rate of 1 mrem/yr, about 3.5x below the base case. The 50-year closure date was found to be achievable using the ventilation option, but construction costs increased due to the additional ventilation shafts required. Since this sensitivity study, it has been determined that the repository pre-closure period will be 100 years, rather than the 50-year period used in the study. This will reduce the required ventilation since the additional delay in backfill installation takes advantage of the reduction in heat rate due to natural decay.

The combination of backfill and cladding credit resulted in a peak dose rate of 0.025 mrem/yr, about 140x below the base case. The two options were essentially independent, with the resulting improvements being multiplicative.

A WP ceramic coating resulted in a 0.09 mrem/yr peak dose rate, about 40x below the base case. When ceramic failure was extended to earlier times, the peak dose rate was 0.6 mrem/yr, about 6x below the base case. In principle, an intact ceramic coating would allow negligible releases; therefore, its PA is essentially an uncertainty analysis. The assumptions used here are an indication of the potential performance available from a long-lived barrier, but are not based on mechanistic or empirical ceramic failure models. These models are being developed.

For the improved CRM with 100 times slower corrosion than the reference material, the calculation showed no releases. When the corrosion rate was only 10 times slower than the base case, the peak dose rate was 0.03 mrem/yr, about 100 times below the base case.

CONCLUSIONS AND DISCUSSION

Based on these sensitivity analyses, the improved corrosion resistant material (C-22) is an attractive option because it improves performance at least two orders of magnitude without requiring extensive design changes or increasing costs. Because of the sensitivity of performance to crevice corrosion, priority should be given to reducing its uncertainty, both experimentally and with process level modeling. The key factor in this uncertainty is the evolution of crevice chemistry, considering the chemistry of dripping water during the last part of the thermal pulse and thereafter.

Cladding has a significant impact (40x) on performance. Historically, cladding integrity has been preserved by temperature limits, as a defense-in-depth factor. Because of its potential "base-case" performance impact, additional testing and literature evaluations of cladding may be appropriate.

Ceramics have the potential for even larger improvements in performance. To realize this potential, both the adherence of ceramic coatings to metal substrates under thermal and handling stresses and the permeability of ceramic coatings under long term exposure to radiation, moisture, and humidity must be established. Experimental efforts and natural analog literature searches have begun to obtain the necessary information.

Backfill with pre-closure ventilation is a viable option to provide mechanical protection of the WP against rock fall without compromising cladding integrity. Increased ventilation adds significant construction cost which needs to be traded against the alternative of increased operating costs for delayed backfill emplacement.

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REFERENCES

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