A COMPARISON OF RISKS DUE TO HLW AND SURF REPOSITORIES IN BEDDED SALT
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ABSTRACT

A methodology was developed to analyze risks from geologic disposal of nuclear wastes. It was applied to estimate the risk due to spent fuel and high-level waste hypothetical repositories in bedded salt. A number of disruptive scenarios were analyzed for each waste type. A comparison between the spent fuel and high-level waste results is presented. The methodology enables one to identify important radionuclides, parameters, and scenarios in terms of their relative contribution to the overall risk or compliance with the proposed EPA Standard.

INTRODUCTION

The Fuel Cycle Risk Analysis Division of Sandia National Laboratories was funded by the Nuclear Regulatory Commission to develop a methodology for use in the analysis of risks from geologic disposal of nuclear wastes. This methodology is applied to two conceptual nuclear waste repositories in bedded salt containing High-Level Waste (HLW) and Spent Un-Reprocessed Fuel (SURF), respectively. A comparison of the risk estimated from the HLW and SURF repositories is presented in this paper.

REPOSITORY DESCRIPTION

The same reference site was used in both the HLW and SURF analyses. This reference site is located in a symmetrical upland valley, half of which is shown in Fig. 1. The basement is assumed to be impermeable to groundwater and is overlain by a sequence of sedimentary rock as shown. A bedded salt deposit having a low permeability is located within the sedimentary sequence and is the host rock for the repository. The groundwater at this reference site is recharged updip and flows through the two layers of sandstone aquifer, and finally discharges into River L.

The assumed radionuclide inventory for a hypothetical repository in bedded salt is given in Table I for each waste type. The design parameters that were different between the two analyses are listed in Table II.

DESCRIPTION OF ANALYSIS

A large number of scenarios was analyzed for the HLW risk analysis.[1] From this, six scenarios were selected for which a risk analysis was performed for the SURF repository.[2] The choice of the SURF scenarios was based largely on the relative risk as estimated in the HLW analysis; it was partly based on the intent to compare, as directly as possible, the application of the methodology to SURF and HLW repositories. The six scenarios are listed in Table III.

A set of thirty-three input variables, i.e., parameters that are thought to control the radionuclides transport, was defined for each analysis. Each parameter was assigned a range and a distribution based on the available data and/or expert opinion. A sampling program,[3] that statistically selects point values from the ranges of variables, was used to construct sets of input values; these sets are referred to as input vectors in the present analysis. For each scenario, 35 input vectors were included in the analysis; i.e., 35 separate calculations were carried out with a series of computer models for each scenario. In general, the sequence of models consisted of a groundwater flow and transport calculation to obtain discharge rates at selected locations, a pathways-biosphere transport model calculation to determine the magnitude of radionuclide releases via different environmental paths, and a dosimetry (health effects) calculation to determine "conditional" cancer risk. The term "conditional" is used to emphasize the assumption of a probability of 1 in computing the risk. One could conceivably multiply the estimated conditional risk by an appropriate probability value to obtain unconditional risk.

The groundwater flow and transport calculations were done using the NWFT/DVM computer model.[4] The output of this model consisted of discharge rates of various radionuclides to River L, and to a well if one were present. These discharge rates serve as input to the Pathways Model[5] which calculates the movement of radionuclides in the surface environment. The surface environment consisted of two zones. The first zone (Zone 1) consisted of a 10-kilometer stretch of the River L and included the well when one was present. The second zone (Zone 2) consisted of a 40-kilometer stretch of River L immediately downstream from the first zone. The output of the Pathways Model consisted of concentrations of radionuclides in the soil, surface water, and sediments. In turn, these concentrations served as input to the Dosimetry and Health Effects Model[6] which calculated the cancer risk based on the curie intake via ingestion, inhalation and external exposure.

DISCUSSION OF RESULTS

Results were obtained in the form of discharge rates and conditional cancer risk. Two discharge locations (Zone 1 and Zone 2) and three pathways (ingestion, inhalation, and external exposure) were monitored. It was not necessary to model the groundwater flow for Scenario 6. The discharge rates and the conditional cancer risk (CCR) data that are presented represent mean values obtained from the results of 35 calculations for each scenario corresponding to the 35 input vectors.

A sensitivity analysis was performed for HLW as well as SURF for Scenarios 2, 4, and 5 (see Table III). The purpose of the sensitivity analysis was to

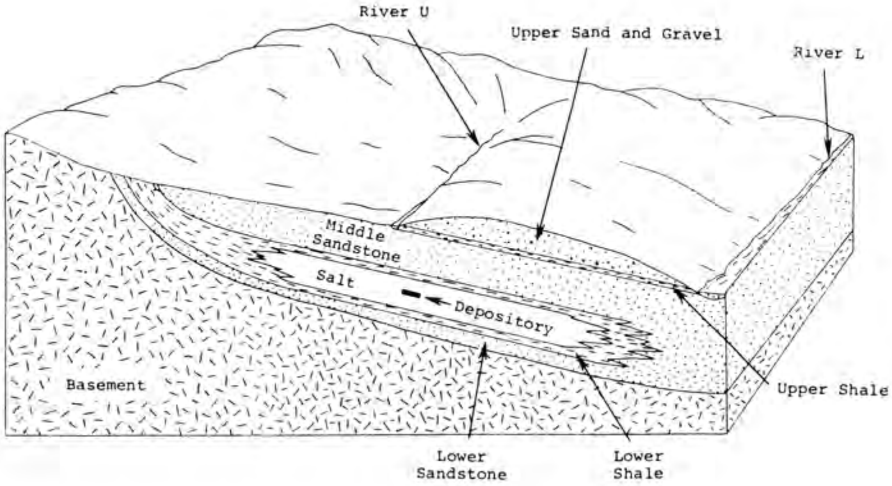

Fig. 1. Schematic Diagram of the Reference Site. (Chu, et al.)

Table I. Radionuclide Inventory for HLW and SURF

Radionuclide	Half-life (yr)	Initial Inventory (Ci)	
		HLW	SURF
Pu 240	6.76×10^{3}	1.68×10^{6}	4.61×10^{7}
U 236	2.39×10^{7}	7.17×10^{1}	3.16×10^{4}
Th 232	1.41×10^{10}	1.54×10^{-2}	3.22×10^{-5}
Ra 228	6.70×10^{0}	2.18×10^{-1}	8.95×10^{-6}
Cm 245	8.27×10^{3}	1.70×10^{5}	3.34×10^{4}
Pu 241	1.46×10^{1}	2.95×10^{7}	4.40×10^{9}
Am 241	4.33×10^{2}	3.34×10^{7}	2.00×10^{8}
Np 237	2.14×10^{6}	2.85×10^{4}	4.04×10^{4}
U 233	1.62×10^{5}	4.06×10^{1}	7.96×10^{0}
Th 229	7.30×10^{3}	8.90×10^{-2}	1.15×10^{-2}
Cm 246	4.71×10^{3}	3.22×10^{4}	6.64×10^{3}
Pu 242	3.79×10^{5}	1.28×10^{3}	1.30×10^{5}
U 238	4.51×10^{9}	1.06×10^{2}	3.03×10^{4}
Pu 238	8.90×10^{1}	1.11×10^{7}	3.08×10^{8}
U 234	2.47×10^{5}	7.89×10^{2}	9.95×10^{4}
Th 230	8.00×10^{4}	1.74×10^{0}	1.68×10^{1}
Ra 226	1.60×10^{3}	1.40×10^{-2}	8.09×10^{-2}
Pb 210	2.10×10^{1}	0.	1.78×10^{-2}
Am 243	7.65×10^{3}	3.19×10^{6}	1.73×10^{6}
Pu 239	2.44×10^{4}	1.25×10^{5}	3.19×10^{7}
U 235	7.10×10^{8}	4.98×10^{0}	1.60×10^{3}
Pa 231	3.25×10^{4}	2.94×10^{1}	3.39×10^{0}
Ac 227	2.16×10^{1}	1.43×10^{1}	1.44×10^{0}
Sn 126	1.00×10^{5}	4.05×10^{4}	5.15×10^{4}
Cs 137	3.02×10^{1}	4.57×10^{9}	--------
I 129	1.70×10^{7}	--------	2.98×10^{3}
Tc 99	2.14×10^{5}	9.12×10^{5}	1.31×10^{6}

Table II. Design Parameter Values for SURF and HLW Repository

PARAMETERS	SURF	HLW
Gross areal extent	$1.2\times10^{7}m^{2}$	$4.5\times10^{6}m^{2}$
Dimensions of excavation	2621m x 5294m	1829m x 2438m
Capacity	90,000 MTHM*	80,000 MTHM*
Number of storage rooms	106	1100
Number of canisters	213,500	35,500
Storage room dimensions		
length	1219m	171m
height	5.8m	5.5m
width	5.3m	5.5m
Thermal loading	$7.4W/m^{2}$	$14.8W/m^{2}$

*MTHM means Metric Tons of Heavy Metal

TABLE III. Risk Analysis Scenarios for HLW and SURF

NUMBER	SCENARIO TITLE
1	Borehole(s) with lower aquifer wells
2	U-tube with upper aquifer wells
3	Dissolution cavity with upper aquifer wells
4	Borehole(s)
5	U-tube
6	Borehole intersecting a canister

attempt to identify the parameters, radionuclides, and processes that dominate the response. A partial rank correlation technique was used to establish the hierarchy of parameters, with either integrated discharge or conditional cancer risk as the basis.

The discharge rates as well as CCRs were found to be the highest for the scenario of a dissolution cavity with upper aquifer wells (Scenario 3). This was true of both the SURF and the HLW repository analyses. Comparisons of peak discharge rate results for Scenarios 3 and 4 are presented in Tables IV and V. The tables give the discharge rates for the four actinide chains and the fission product radionuclides. In Scenario 3, peak discharge rates were the highest for Am 243, Pu 239, and Tc 99 in the SURF analysis; and were the highest for Am 243 in the HLW analysis. The highest discharge rates for SURF were an order of magnitude larger than the corresponding HLW discharge rates. In Scenario 4, Tc 99 had the highest discharge rates for both waste types. The discharge rates in Scenarios 4, 5, and 6 (i.e., scenarios without aquifer wells) were found to be significantly lower than those from Scenarios 1, 2, and 3. The mean risk curves for Zone 1 in Scenario 3 are compared in Fig. 2. The peak ingestion risks are 3×10^{-1} for SURF and 5×10^{-2} for HLW. The peak CCRs due to ingestion for all six scenarios and both zones are summarized in Table VI. The Zone 1 CCR estimates for Scenarios 1, 2, and 3 are within an order of magnitude of one another. The remaining three scenarios pose conditional risks in Zone 1 that are three to four orders of magnitude lower than the first three. The Zone 2 CCR values are relatively small for all six scenarios. The scatter in the model output (discharge rate and CCR) could generally be traced back to the range of the input variables. It should be noted that, in general, highest instantaneous discharge rates or CCRs do not necessarily imply the largest integrated discharges or absolute risks, respectively.

Depending on whether integrated discharge or CCR is used as the basis, several or a few variables appear to dominate the response in the sensitivity analysis. The difference is attributed to the fact that CCR estimates include the effect of toxicity of each radionuclide. When the integrated discharge is used as the basis, the distribution coefficients (k_ds) of several radionuclides appear significant. In addition, one or more of the following parameters - solubility limit, leach time, hydraulic conductivity of the aquifers, and the amount of radionuclide at the source - were found to be important in the three sensitivity scenarios. When CCR is used as the basis, the number of radionuclides for which the k_d value is shown to be relatively important drops significantly. In fact, the relative order of importance for many of the variables changes. For example, Ra 226 becomes a more dominant radionuclide when CCR is used, whereas certain other radionuclides rank higher when total integrated discharge is the basis. The differences between HLW and SURF results can, for the most part, be attributed to differences in the initial radionuclide inventory. This difference will also lead to different production rates of daughter radionuclides which may dominate the long term releases.

The requirements in the draft Environmental Protection Agency (EPA) draft Standard are expressed in terms of probabilities of release and integrated radionuclide releases over a period of 10,000 years. To assess the applicability of the hypothetical site analyzed, complementary cumulative distribution functions (CCDF) were generated[1,2] based on the calculated consequences from each of the six scenarios. Shown in Fig. 3 are the composite CCDF curves for SURF and HLW. The abcissa represents the release ratio, which is integrated release normalized to the draft Standard. The ordinate may be interpreted as the fraction of total number of vectors analyzed that produce a release ratio greater than the corresponding abcissa value. Abcissa values greater than 1 represent a violation of the limits prescribed in the draft Standard. The scenarios and the input vectors that produce a violation are identified by this methodology. It is noted that the scenario probabilities are very difficult to estimate and that the results shown in Fig. 3 should be considered as a demonstration of the methodology at this stage.

CONCLUSIONS

A methodology that was initially developed for risk assessment of HLW repositories was found to be equally applicable to SURF repositories. For the six scenarios that were analyzed, the scenario of a dissolution cavity extending to a repository and connecting it to an upper aquifer well (Scenario 3) was found to result in the maximum integrated discharge and conditional cancer risk over a period of 100,000 years. Relatively high risks were predicted for Scenarios 1 and 2, whereas Scenarios 4, 5, and 6 had low releases and conditional cancer risks. The study also demonstrated how the degree and order of importance of various parameters and radionuclides can change when the basis for estimating the risk is changed.

Based on the present analysis, it appears that over a period of 100,000 years the risks associated with the disposal of SURF are higher than those for HLW for the assumed repository configuration at a hypothetical bedded salt site.

Whereas the methodology could be extended to other media, one is cautioned against generalizing the conclusions of this study to repositories in media other than bedded salt. It is submitted that studies such as the one presented in this paper help identify important parameters and scenarios for high-level nuclear waste disposal, which in turn can help focus future research efforts in that area.

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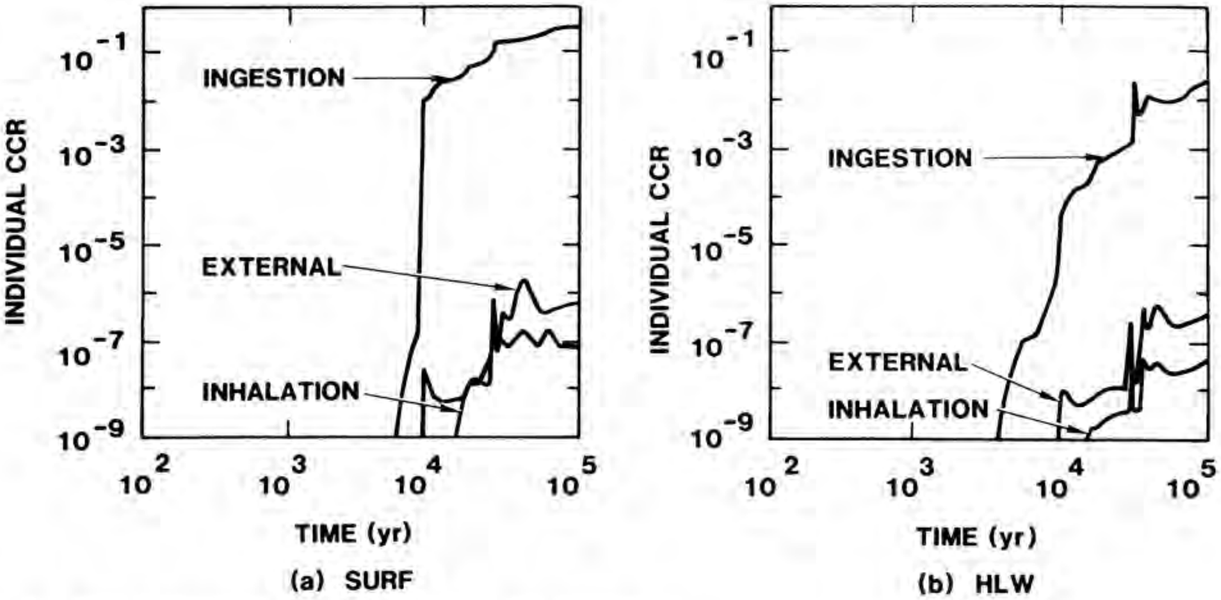

Fig. 2. Mean Conditional Cancer Risk Curves for Scenario 3.

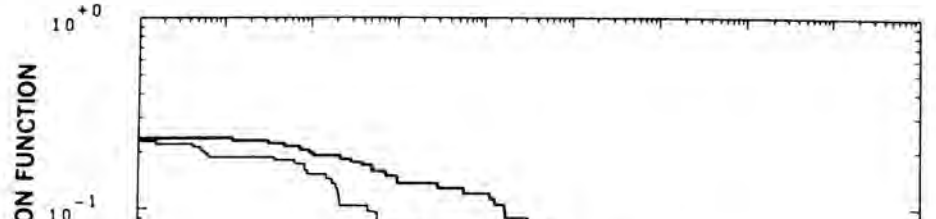

Fig. 3. Normalized Composite CCDF Curves for HLW and SURF.

Table IV. Discharge Rate Summary for Scenario 3 (Dissolution cavity with upper aquifer wells)

Chain / Result	4n+0		4n+1		4n+2		4n+3		Fission Products	
	SURF	HLW	SURF	HLW	SURF	HLW	SURF	HLW	SURF	HLW
Radionuclide with Highest Discharge Rate	Pu 240	Pu 240	Th 229	Cm 245 Am 241	Pu 242	U 234	Pu 239 Am 243	Am 243	Tc 99	Tc 99
Magnitude of Peak Rate (Ci/day)	$2x10^{-3}$	$3x10^{-4}$	$2x10^{-4}$	$4x10^{-4}$	$3x10^{-4}$	$5x10^{-5}$	$2x10^{-2}$	$5x10^{-3}$	$2x10^{-2}$	$4x10^{-3}$
Time of Peak Rate (yrs)	$2x10^{4}$	$2x10^{4}$	$6x10^{4}$	$3x10^{4}$	$6x10^{4}$	$3x10^{4}$	$6x10^{4}$ $3x10^{4}$	$3x10^{4}$	$6x10^{4}$	$4x10^{4}$
Radionuclides with $<10^{-9}$ Discharge Rate	Th 232 Ra 228 $<10^{-7}$	Th 232 Ra 228	---	---	Pu 238 $<10^{-8}$	Pu 238	---	---	---	Cs 137

Table V. Discharge Rate Summary for Scenario 4 (Boreholes)

Chain / Result	4n+0		4n+1		4n+2		4n+3		Fission Products	
	SURF	HLW	SURF	HLW	SURF	HLW	SURF	HLW	SURF	HLW
Radionuclide with Highest Discharge Rate	Pu 240	Pu 240	Np 237	Cm 245 Am 241	Ra 226	Ra 226	Pu 239	Pu 239	Tc 99	Tc 99
Magnitude of Peak Rate (Ci/day)	$3x10^{-6}$	$1x10^{-5}$	$7x10^{-7}$	$1x10^{-7}$	$2x10^{-5}$	$2x10^{-7}$.	$4x10^{-5}$	$3x10^{-5}$	$2x10^{-4}$	$4x10^{-5}$
Time of Peak Rate (yrs)	$3x10^{+4}$	$3x10^{4}$	$2x10^{4}$	$4x10^{4}$	$5x10^{4}$	$5x10^{4}$	$7x10^{4}$	$3x10^{4}$	$3x10^{4}$	$3x10^{4}$
Radionuclides with $<10^{-9}$ Discharge Rate	Th 232 Ra 228	Th 232 Ra 228	---	---	Pu 238	Pu 238 Cm 246	U 235	U 235 Ac 227	---	Cs 137

Table VI. Peak CCR's Due to Ingestion During the 10^2 - 10^5 Year Period; Zone 1 and Zone 2 Results for SURF and HLW.

Scenario Description		Borehole(s) with Lower Aquifer Well	U-tube with Upper Aquifer Wells	Dissolution Cavity with Wells	The Borehole(s)	The U-Tube	Borehole Intersecting a Canister
Scenario #	SURF	1	2	3	4	5	6
	HLW	4	10	12	3	9	8
Zone 1 CCR (ingestion)	SURF	8×10^{-2}	2×10^{-1}	3×10^{-1}	1×10^{-6}	2×10^{-6}	3×10^{-6}
	HLW	2×10^{-3}	2×10^{-2}	5×10^{-2}	2×10^{-8}	2×10^{-7}	1×10^{-6}
Zone 2 CCR (ingestion)	SURF	8×10^{-7}	4×10^{-6}	7×10^{-6}	1×10^{-6}	1×10^{-6}	2×10^{-6}
	HLW	2×10^{-8}	6×10^{-7}	4×10^{-6}	2×10^{-8}	2×10^{-7}	1×10^{-6}

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