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One-Dimensional Human Intrusion Analysis of the Paleozoic Aquifer, as Part of the Site Suitability Effort at Yucca Mountain, Nevada

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July 1991

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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M. A. McGraw
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EXECUTIVE SUMMARY

A programmatic need was identified by the U.S. Department of Energy, through the Office of Civilian Radioactive Waste Management, for a preliminary "site suitability" performance assessment for the Yucca Mountain site. The effort is designed to integrate field, laboratory, and modeling information to identify key technical issues that need to be addressed and determine which field parameters are important during site characterization. This report examines one-dimensional transport of radionuclides in the Paleozoic aquifer. The problem is based on a human intrusion scenario which introduces a point source of radionuclides directly into the aquifer. This effort is only one part of the larger site suitability effort.

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INTRODUCTION

The U.S. Department of Energy is currently evaluating Yucca Mountain as the potential site for a high-level nuclear waste repository. One of the major efforts for evaluation of the site, termed "site suitability," is an effort designed to integrate field, laboratory, and modeling information to identify key technical issues that need to be addressed and determine which field parameters are important during site characterization.

This study is a computer modeling analysis of the saturated zone at Yucca Mountain. Two aquifers of primary concern were identified by Winograd and Thordarson (1975) in the vicinity of Yucca Mountain. The first is the Tertiary or tuff aquifer, which extends under Yucca Flat, Frenchman Flat, and Jackass Flats, and is believed to pinch out south of Yucca Mountain. This aquifer is the sole source of groundwater in western Jackass Flats. The second is the Paleozoic or lower carbonate aquifer, which resides in limestone and dolomite. This aquifer is believed to extend under most of the Nevada Test Site (NTS) and provides the sole source of groundwater for parts of the NTS.

Several studies have examined the regional hydrology around Yucca Mountain; however, no calculations have been made to predict the movement of radionuclides. Therefore, the computer modeling portion of the site suitability effort for the saturated zone examines transport of radionuclides from the repository to the accessible environment, which is defined by the regulations to be a 5-km radial area around the repository (40 CFR 191). The regulations state that only a limited amount of radionuclides can reach the accessible environment within 10,000 years of waste emplacement.

Two studies are being conducted for the saturated zone transport of radionuclides as part of the site suitability effort. The first is based on the regional model (Czarnecki 1985) previously calculated and examines radionuclide transport at the interface between the saturated and the unsaturated zone. This effort is being conducted at Sandia National Laboratory.

The second is the focus of this report, which examines one-dimensional transport of radionuclides in the Paleozoic aquifer. This problem is based on a human intrusion scenario, which introduces a point source of radionuclides directly into the aquifer. A human intrusion scenario was used because Winograd and Thordarson (1975) indicated that the gradient between the Paleozoic aquifer and the overlying tuff aquifer, if any, is upward. A downward gradient would be necessary to transport radionuclides from the unsaturated zone through the tuff aquifer into the Paleozoic aquifer; therefore, only disturbed-case scenarios will introduce contaminants into the lower aquifer when both aquifers are present.

A baseline scenario was calculated, along with a sensitivity analysis for parameters for which ranges are available. The purpose of the sensitivity analysis was to help determine to what parameters the model is most sensitive, and therefore, which parameters should receive high consideration in future site data collection. The results and conclusions from the baseline case and the sensitivity analysis are contained in this report.

PREVIOUS WORK

The most detailed analysis of the regional hydrology was conducted by Winograd and Thordarson (1975). They examined the hydrogeologic, hydrochemical, and isotopic relationships for the groundwater basin around the NTS. The study showed that the regional movement of groundwater was controlled by the lower clastic aquitard, the lower carbonate aquifer, and the tuff aquifer. The general flow direction for the region is to the southwest.

The regional flow system around Yucca Mountain was modeled by Wadell (1982) and Czarnecki and Wadell (1984). The study by Czarnecki and Wadell was a submodel of the work by Wadell and incorporated additional well data from Yucca Mountain and Franklin Lake Playa. One of the reasons for construction of a submodel was to allow calculation of radionuclide transport, which would require finer gridding than the original model by Wadell. Czarnecki and Wadell used a parameter estimation technique to model the flow system and perform a sensitivity analysis on fluxes and transmissivities. The hydraulic heads calculated by Czarnecki and Wadell matched most of the well data within 7 m.

Another regional study examined the effects of increased recharge, resulting from climatic change, on the groundwater system (Czarnecki 1985). This study showed that the water table could rise from an increase in precipitation, but that even at 100% increase it would not intercept the potential repository as currently proposed.

HYDROLOGIC MODEL

This problem was developed for the site suitability effort based on information from Well UE-25p#1 (Craig and Johnson 1984; Craig and Robison 1984), which is the only well near Yucca Mountain that penetrates the Paleozoic aquifer. Additional limited information is available on the Paleozoic aquifer from wells located on the NTS. Well UE-25p#1 was drilled to a depth of 1805 m, and includes 561 m of the Paleozoic aquifer. Because data from this well are limited, a one-dimensional, analytic solution was chosen to evaluate transport in this aquifer. The analytic solution chosen assumes a single phase, constant density, constant viscosity, and incompressible fluid. The medium is assumed to be homogeneous, isotropic, and isothermal.

The EPASTAT computer code (Version 4.0) was used for this analysis (Eslinger and Sagar 1988). The code was developed to solve one-dimensional flow and radionuclide transport problems for the Basalt Waste Isolation Project. The model assumes flow information is known, and the transport of radionuclides is based on an analytical solution that requires numerical integration. The code assumes that radionuclide transport is one-dimensional along the direction of flow, conserves mass, and obeys Fick's law. The analysis uses a flow tube approach that includes water velocity, retardation, dispersion, and diffusion. Radionuclide decay is included, but chain decay is not.

The use of numerical integration for calculating radionuclide concentrations is a limitation in determining radionuclide arrival times for short travel distances. The arrival time of the radionuclides is determined when the concentration exceeds a threshold, set to 1×10^{-10} Ci/m^3 for this analysis. Checks are made for arrival of radionuclides only at numerical integration times. Thus, arrival times are accurate only to within a few years. Results for shorter distances in this analysis should be considered as a general scoping analysis.

SOURCE TERM

The radionuclides modeled include ^{99}Tc, ^{129}I, ^{135}Cs, ^{237}Np, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am. The source terms were generated by Lawrence Berkeley Laboratory and provided in tabular format for input into the models (Appendix A). The source terms generated assumed no release for 500 years after waste emplacement and that the contents of one entire waste package entered the Paleozoic aquifer. A flow rate of 3000 m^3/yr was used to calculate the source term. This high flow rate was intended to represent increased flow from the aquifer.

The source terms were input directly into the model, and chain decay was not accounted for in the transport model. By not including chain decay, the large inventory of ^{241}Am, which has a half-life of 432 years, is removed from the system rapidly. The decay product ^{237}Np has a half-life of 2.1×10^7 years. Inclusion of chain decay could significantly alter the cumulative release results.

INPUT PARAMETERS

The parameters used in the model were based on data from Well UE-25p#1, NTS data, and analog information. Transmissivity values for the tuff and Paleozoic aquifers were determined from aquifer tests conducted over several different intervals. For the Paleozoic aquifer, four different intervals were tested (Craig and Robison 1984). The transmissivity data from the aquifer test were used to calculate the hydraulic conductivity. The low and high hydraulic conductivity values of 8.5 m/yr and 1144.7 m/yr, respectively, from the four sections tested were used in the calculations. No information is available to indicate that the values used are bounding values. The well report indicates that most of the flow is actually transmitted by one or two fractures. Fractures were not incorporated into this model; such incorporation could significantly alter the results.

Porosity values for the aquifer were based on 25 samples from the NTS (Winograd and Thordarson 1975). The base value used in this analysis was 0.01, which is considered a lower bound. The value 0.09 was used in the

sensitivity analysis, which may or may not be an upper bound. Values for the rock density were derived from analog information (Jackson 1970).

The dip of the aquifer was inferred to be between 4% and 6% based on the bed dip of overlying units (DOE 1988). This information was used to estimate a pressure gradient and did not incorporate the information from Winograd and Thordarson (1975), which indicates that the pressure gradient could be upward. The upward gradient was omitted because this analysis was one-dimensional.

No information was available from field or laboratory experiments for longitudinal dispersivity. Therefore, based on values commonly used in the literature, the initial longitudinal dispersivity was assigned a value of 1. Values of 10 and 100 were also used in the sensitivity analysis.

The transport model included sorption for six of the eight radionuclides analyzed. The values used were determined from laboratory experiments conducted at Los Alamos National Laboratory[(a)]. The calculations were based on analysis of the mineral calcite of the Bull Frog unit in water from Well J-13. These values are only an analogue and therefore approximate values. The EPASTAT code uses the sorption values in the form of a retardation coefficient and does not incorporate effects such as competitive sorption.

The arrival time of the radionuclides was calculated at 5000 m based on the definition of the accessible environment. Because some of the radionuclides were heavily retarded, eight additional points between 25 and 7500 m were examined to develop a conceptual image of the plume. Based on the regulatory requirement, the arrival time used was 10,000 years. The analysis was also extended to 100,000 years as part of the sensitivity analysis.

(a) Patera, E. S. 1991. Memo on Solubility and Sorption Information to Support Performance Assessment Calculations. Los Alamos National Laboratory, Los Alamos, New Mexico.

RESULTS

Three different results are obtained from this analysis. The first is the arrival time of radionuclides at a specified distance. The second is the concentration of the radionuclide at a specified distance and time. The third is the cumulative flux of the radionuclides at a specified distance and time reported in terms of a ratio with the U.S. Environmental Protection Agency (EPA) limit (40 CFR 191). Values of the ratio above 1.0 violate the limits set by the EPA. The ratio serves as a relative index of the potential harm from a release of radionuclides. Thus, the release of a small quantity of a dangerous contaminant could produce a larger EPA ratio than a larger release of a less hazardous contaminant. Twelve simulation cases were done, with Cases 1 and 7 as the base cases. Table 1 shows all the cases and the variations in parameters. Finally, a sensitivity analysis was performed using several different parameter sets.

BASE CASES

Cases 1 and 7 were the base cases. The first case used the lowest values of porosity, hydraulic conductivity, and longitudinal dispersivity, and the average value for the gradient. The seventh case was identical to the first except it used the largest value of hydraulic conductivity. Sorption was included in all simulations, and the sorption values used are reported in Table 2. The first and seventh simulations evaluated releases at 5000 m at the end of 10,000 years.

Examination of Cases 1 and 7 at 10,000 years over a range of distances gives a general feel for the movement of the different radionuclides (Table 3 and 4). ^{99}Tc and ^{129}I are not retarded and move rapidly through the system. In Cases 1 and 7 , ^{99}Tc and ^{129}I reach the accessible environment around 90 and 3 years after release. Figure 1 is a plot of distance versus arrival time for these two species and shows that the distance covered is directly proportional to the time elapsed. This implies a linear velocity of 55 m/yr for Case 1 and 1670 m/yr for Case 7.

TABLE 1. Variations of Parameters in Cases 1 through 12

Case	Description	Hydr. Cond. (m/yr)	Por.	Grad.	Long. Disp. (m)	Darcy Flux (m/yr)	Distances Run (m)	Times Run (yr)
1	Baseline (Low Hydr. Conductivity)	8.578	0.01	0.06	1	0.5147	25, 50, 100, 250, 500 1000, 2500, 5000, 7500	5000, 10000, 100000
2	Increased Porosity	8.578	0.09	0.06	1	0.5147	25, 5000	10000
3	Increased Long. Dispersivity	8.578	0.01	0.06	10	0.5147	25, 5000	10000
4	Greatly Increased Long. Disp.	8.578	0.01	0.06	100	0.5147	25, 5000	10000
5	Decreased Hydraulic Gradient	8.578	0.01	0.04	1	0.3431	25, 5000	10000
6	Increased Hydraulic Gradient	8.578	0.01	0.08	1	0.6862	25, 5000	10000
7	Baseline (High Hydr. Conductivity)	1144.76	0.01	0.06	1	68.6854	25, 50, 100, 250, 500 1000, 2500, 5000, 7500	10000
8	Increased Porosity	1144.76	0.09	0.06	1	68.6854	25, 5000	10000
9	Increased Long. Dispersivity	1144.76	0.01	0.06	10	68.6854	25, 5000	10000
10	Greatly Increased Long. Disp.	1144.76	0.01	0.06	100	68.6854	25, 5000	10000
11	Decreased Hydraulic Gradient	1144.76	0.01	0.04	1	45.7904	25, 5000	10000
12	Increased Hydraulic Gradient	1144.76	0.01	0.08	1	91.5808	25, 5000	10000

TABLE 2. Sorption Coefficients

Element	Kd	
Technetium	0	Non-Sorption
Iodine	0	Non-Sorption
Cesium	5	Sorption
Neptunium	20	Sorption
Plutonium	50	Sorption
Americium	100	Sorption

TABLE 3. Case 1: Arrival Times for a Range of Distances at 10,000 Years

(Initial release occurs at 502 years)

	25 m	50 m	100 m	250 m	500 m	1000 m	2500 m	5000 m	7500 m
^{99}Tc	503	503	505	505	511	518	543	591	634
^{129}I	503	503	505	505	511	518	543	588	634
^{135}Cs	644	919	1670	4400	9590	(a)	(a)	(a)	(a)
^{237}Np	1080	2200	5160	(a)	(a)	(a)	(a)	(a)	(a)
^{239}Pu	1690	4220	(a)	(a)	(a)	(a)	(a)	(a)	(a)
^{240}Pu	1670	4200	(a)	(a)	(a)	(a)	(a)	(a)	(a)
^{241}Am	2960	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
^{243}Am	3040	8280	(a)	(a)	(a)	(a)	(a)	EPA Boundary	(a)

(a) Did not reach the boundary within 10,000 years.

For the unretarded radionuclides, the tables indicate how far the radionuclides travel in the 10,000 years. Comparison of Tables 3 and 4 demonstrates that, in general, the higher hydraulic conductivity shortens the travel time to the accessible environment, resulting in an increased release of radionuclides to the accessible environment. For example, in Case 1 ^{240}Pu traveled about 50 m, while in Case 7 it traveled more than 5000 m. A distance versus time plot for the retarded radionuclides (^{135}Cs, ^{237}Np, ^{239}Pu, and ^{240}Pu) is shown in Figure 2. The figure shows that the relationship is slightly curved, which is due to the effects of sorption.

TABLE 4. Case 7: Arrival Times for a Range of Distances at 10,000 Years

(Initial release occurs at 502 years)

	25 m	50 m	100 m	250 m	500 m	1000 m	2500 m	5000 m	7500 m
^{99}Tc	503	503	503	503	503	503	503	503	505
^{129}I	503	503	503	503	503	503	503	503	505
^{135}Cs	505	508	512	534	572	657	926	1390	1860
^{237}Np	508	518	541	626	784	1120	2200	4050	5940
^{239}Pu	512	534	587	784	1160	1980	4620	9200	(a)
^{240}Pu	512	534	584	784	1160	1980	4620	9200	(a)
^{241}Am	522	560	664	1060	1820	3510	9180	(a)	(a)
^{243}Am	524	565	679	1080	1850	3520	8840	(a)	(a)
								EPA Boundary	

(a) Did not reach the boundary within 10,000 years.

In contrast to travel time results, which just indicate when the radionuclide arrives, the EPA ratio provides information about the relative hazards of radionuclides. The EPA ratios for Cases 1 and 7 are reported in Tables 5 and 6, respectively. The EPA ratio is a normalized sum of cumulative releases for all radionuclides. The tables provide the contribution to the sum by individual radionuclides.

Chain decay was not modeled in this analysis. Incorporation of the ^{241}Am-to-^{237}Np and ^{243}Am-to-^{239}Pu, single-step chains would provide a much better estimate of the cumulative releases of ^{237}Np and ^{239}Pu because both ^{243}Am and ^{241}Am have relatively short half-lives.

SENSITIVITY ANALYSES

The sensitivity analysis was performed to help determine which parameters need further characterization and could be considered in the data collection activities for site suitability. Table 1 shows the different cases examined. Of the variables analyzed, hydraulic conductivity and longitudinal dispersivity had the largest impact on the results.

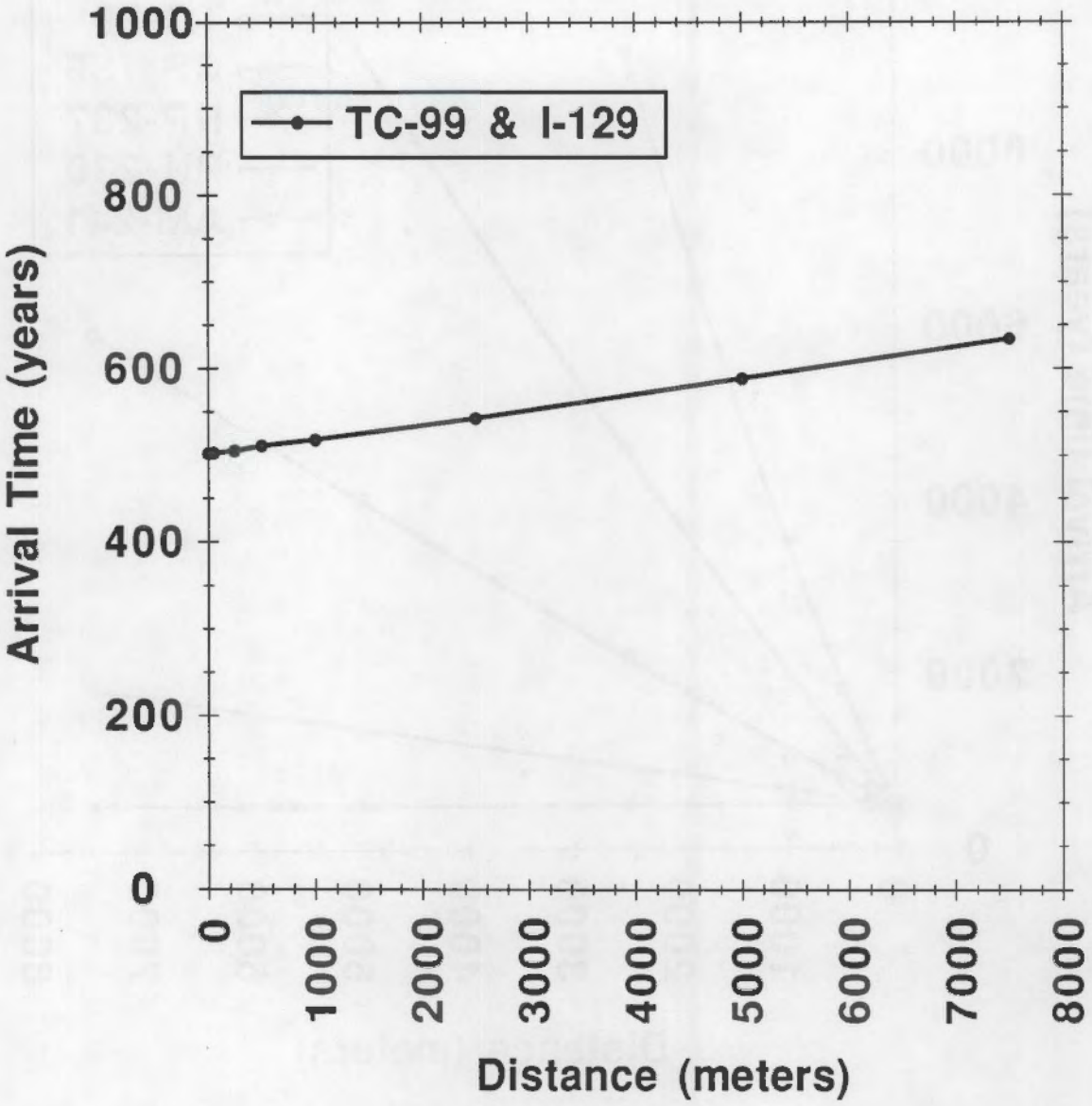

FIGURE 1. Case 1 Transport of Unretarded Nuclides

The effect of increasing porosity from 0.01 to 0.09 was examined in Cases 2 and 8. Because not all of the nuclides arrived at 5000 m in 10,000 years, results are also reported at 25 m to provide a general indication of the trend. The travel time results at 5000 and 25 m are shown in Tables 7 and 8, respectively. In both cases, the results vary between unretarded and retarded radionuclides. For unretarded radionuclides, an increase in porosity

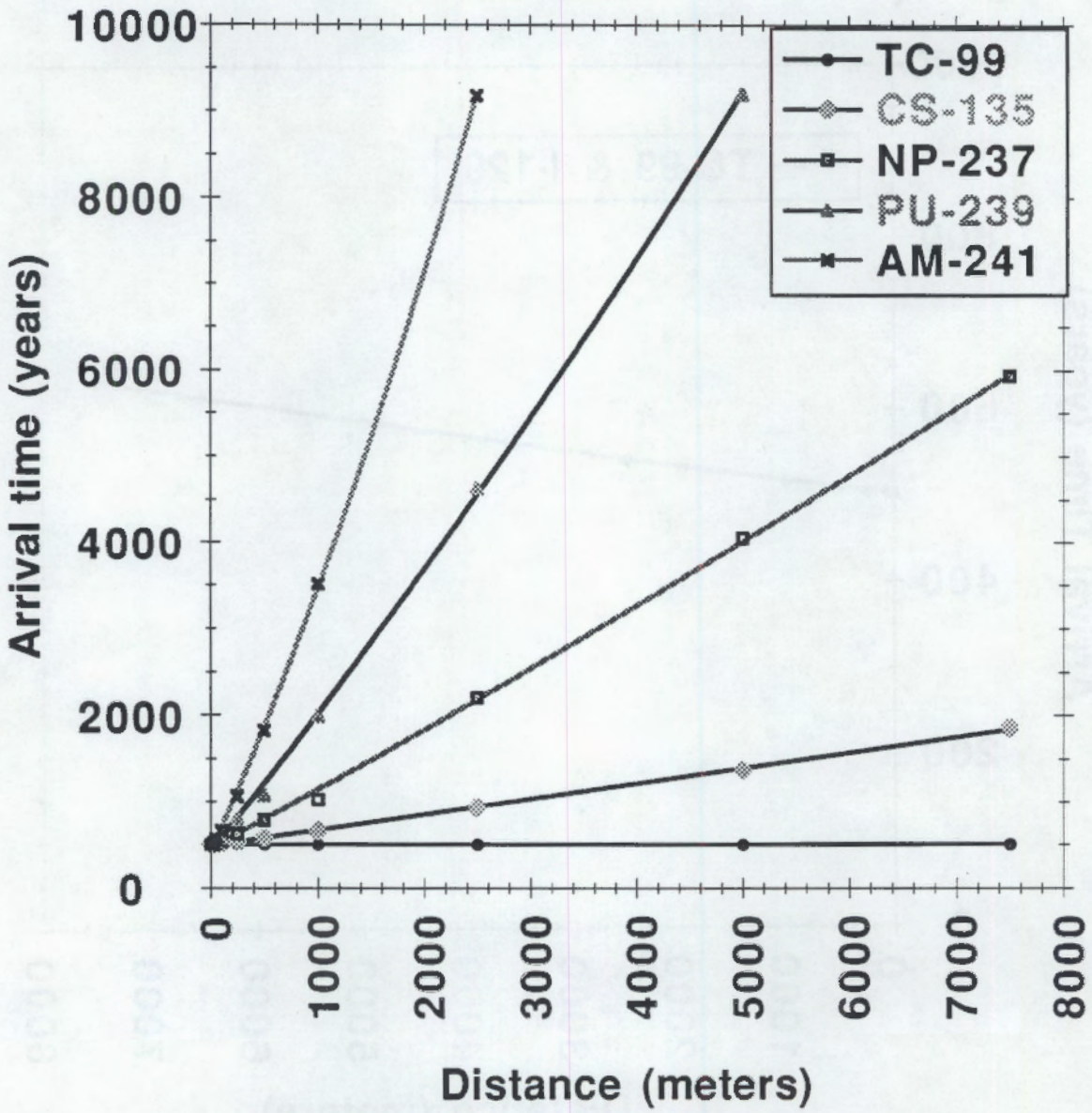

FIGURE 2. Case 7 Transport of All Radionuclides

increases the travel time. For example, in Table 7 the travel time for ^{99}Tc increases from 90 to 770 years after its initial release at year 502. For the retarded radionuclides the opposite is true and the travel time decreases between 10 to 200 years with an increase in porosity. The decrease in travel time is due to an increase in the retardation coefficient as a function of

TABLE 5. Case 1: EPA Ratios for a Range of Distances at 10,000 Years

	25 m	50 m	100 m	250 m	500 m	1000 m	2500 m	5000 m
^{99}Tc	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
^{129}I	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
^{135}Cs	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0
^{237}Np	8.4	5.1	0.2	0.0	0.0	0.0	0.0	0.0
^{239}Pu	800.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0
^{240}Pu	720.0	8.6	0.0	0.0	0.0	0.0	0.0	0.0
^{241}Am	<0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
^{243}Am	1.3	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
								EPA Boundary

TABLE 6. Case 7: EPA Ratios for a Range of Distances at 10,000 Years

	25 m	50 m	100 m	250 m	500 m	1000 m	2500 m	5000 m	7500 m
^{99}Tc	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
^{129}I	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
^{135}Cs	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
^{237}Np	12.0	12.0	12.0	12.0	11.0	11.0	9.3	6.8	4.2
^{239}Pu	2800.0	2700.0	2700.0	2600.0	2400.0	2100.0	1200.0	0.2	0.0
^{240}Pu	3200.0	3100.0	3100.0	2900.0	2700.0	2200.0	1100.0	0.1	0.0
^{241}Am	1000.0	850.0	610.0	240.0	49.0	2.1	<0.01	0.0	0.0
^{243}Am	110.0	110.0	100.0	92.0	77.0	52.0	0.0	0.0	0.0
								EPA Boundary	

increased porosity. This increase is also illustrated in Case 8, where there is an increase in the hydraulic conductivity. The accuracy of the computed times at 25 m is within 4 years.

The EPA ratios at 5000 and 25 m are shown in Tables 9 and 10, respectively. For Case 2, the ratios are either identical or slightly higher than the ratios obtained from Case 1 for the sorbed nuclides. In Case 8, however, there is a large increase in the EPA ratio for plutonium. This increase is

TABLE 7. 10,000-year Arrival Times for the Sensitive Analysis at 5000 m

(Initial release occurs at 502 years)

	^{99}Tc	^{129}I	^{135}Cs	^{237}Np	^{239}Pu	^{240}Pu	^{241}Am	^{243}Am
Baseline (Low Hydr. Conductivity)	591	588	(a)	(a)	(a)	(a)	(a)	(a)
Increased Porosity (n = 0.09)	1280	1270	(a)	(a)	(a)	(a)	(a)	(a)
Increased Long. Dispersivity (10)	569	569	(a)	(a)	(a)	(a)	(a)	(a)
Greatly Increased Long. Disp. (100)	534	534	(a)	(a)	(a)	(a)	(a)	(a)
Decreased Hydraulic Gradient (0.04)	632	632	(a)	(a)	(a)	(a)	(a)	(a)
Increased Hydraulic Gradient (0.08)	568	568	(a)	(a)	(a)	(a)	(a)	(a)
Baseline (High Hydr. Conductivity)	503	503	1390	4050	9200	9200	(a)	(a)
Increased Porosity (n = 0.09)	509	509	1320	3770	8500	8510	(a)	(a)
Increased Long. Dispersivity (10)	503	503	1190	3260	6980	6990	(a)	(a)
Greatly Increased Long. Disp. (100)	503	503	819	1780	3300	3290	7080	6340
Decreased Hydraulic Gradient (0.04)	503	503	1830	5820	(a)	(a)	(a)	(a)
Increased Hydraulic Gradient (0.08)	503	503	1170	3170	7030	7030	(a)	(a)

(a) Did not reach the boundary within 10,000 years.

TABLE 8. 10,000-year Arrival Times for the Sensitive Analysis at 25 m

(Initial release occurs at 502 years)

	^{99}Tc	^{129}I	^{135}Cs	^{237}Np	^{239}Pu	^{240}Pu	^{241}Am	^{243}Am
Baseline (Low Hydr. Conductivity)	503	503	644	1080	1690	1670	2960	3040
Increased Porosity (n = 0.09)	505	505	634	1040	1590	1580	2750	2840
Increased Long. Dispersivity (10)	503	503	524	598	679	676	831	888
Greatly Increased Long. Disp. (100)	503	503	505	515	522	522	539	546
Decreased Hydraulic Gradient (0.04)	503	503	714	1360	2260	2240	4390	4280
Increased Hydraulic Gradient (0.08)	503	503	610	942	1400	1390	2310	2420
Baseline (High Hydr. Conductivity)	503	503	505	508	512	512	522	524
Increased Porosity (n = 0.09)	503	503	505	508	512	511	520	522
Increased Long. Dispersivity (10)	503	503	503	505	505	505	505	508
Greatly Increased Long. Disp. (100)	503	503	503	503	503	503	503	503
Decreased Hydraulic Gradient (0.04)	503	503	505	511	518	518	530	534
Increased Hydraulic Gradient (0.08)	503	503	505	508	511	511	518	518

due to the decreased travel times, which increase the amount of mass passing through the system. Although it may appear that an increase in porosity is significant for plutonium, it is important to realize that the large changes are mostly due to the change in hydraulic conductivity.

The longitudinal dispersivity was varied in Cases 3, 4, 9, and 10. In Cases 3 and 9, the parameter was increased from 1 to 10, and in Cases 4 and 10

TABLE 9. 10,000-year EPA Ratios for the Sensitivity Analysis at 5000 m

	^{99}Tc	^{129}I	^{135}Cs	^{237}Np	^{239}Pu	^{240}Pu	^{241}Am	^{243}Am
Baseline (Low Hydr. Conductivity)	1.3	0.33	0	0	0	0	0	0
Increased Porosity (n = 0.09)	1.3	0.33	0	0	0	0	0	0
Increased Long. Dispersivity (10)	1.3	0.33	0	0	0	0	0	0
Greatly Increased Long. Disp. (100)	1.3	0.33	0	0	0	0	0	0
Decreased Hydraulic Gradient (0.04)	1.3	0.33	0	0	0	0	0	0
Increased Hydraulic Gradient (0.08)	1.3	0.33	0	0	0	0	0	0
Baseline (High Hydr. Conductivity)	1.3	0.33	0.34	6.8	0.17	0.13	0	0
Increased Porosity (n = 0.09)	1.3	0.33	0.34	7.2	89	70	0	0
Increased Long. Dispersivity (10)	1.3	0.33	0.33	6.7	19	15	0	0
Greatly Increased Long. Disp. (100)	1.3	0.33	0.34	6.8	150	120	<0.01	<0.01
Decreased Hydraulic Gradient (0.04)	1.3	0.33	0.33	4.2	0	0	0	0
Increased Hydraulic Gradient (0.08)	1.4	0.33	0.35	8	530	440	0	0

TABLE 10. 10,000-year EPA Ratios for the Sensitivity Analysis at 25 m

	^{99}Tc	^{129}I	^{135}Cs	^{237}Np	^{239}Pu	^{240}Pu	^{241}Am	^{243}Am
Baseline (Low Hydr. Conductivity)	1.3	0.33	0.35	8.4	800	720	<0.01	1.3
Increased Porosity (n = 0.09)	1.3	0.33	0.35	8.6	930	1600	<0.01	2.4
Increased Long. Dispersivity (10)	1.3	0.32	0.35	8.5	1200	1100	2.5	17
Greatly Increased Long. Disp. (100)	1.4	0.35	0.88	9.6	1800	2000	130	54
Decreased Hydraulic Gradient (0.04)	1.3	0.33	0.34	6.7	230	190	<0.01	0.028
Increased Hydraulic Gradient (0.08)	1.3	0.33	0.35	9.3	1200	1200	0.018	7
Baseline (High Hydr. Conductivity)	1.3	0.33	0.36	12	2800	3200	1000	110
Increased Porosity (n = 0.09)	1.3	0.33	0.36	12	2800	3200	1000	110
Increased Long. Dispersivity (10)	1.3	0.32	0.36	11	2700	3100	1000	110
Greatly Increased Long. Disp. (100)	1.5	0.36	0.37	12	2800	3200	1000	110
Decreased Hydraulic Gradient (0.04)	1.3	0.33	0.36	12	2700	3200	920	110
Increased Hydraulic Gradient (0.08)	1.3	0.33	0.36	12	2800	3200	1000	110

the parameter was increased to 100. An increase in the longitudinal dispersivity significantly decreased the travel times of all the radionuclides. The effect of longitudinal dispersivity was evident at distances of both 5000 and 25 m (Tables 7 and 8), except for Cases 9 and 10 at 25 m; this difference is due to a high Darcy velocity and the accuracy of the computed arrival times. The decrease in travel time is evident for ^{240}Pu. In Table 7 it decreases from a travel time of 9200 years in the base case to 6990 and 3290 years in Cases 9 and 10, respectively, a change of almost 6000 years. The other significant impact from an increase in longitudinal dispersivity is that the radionuclides are transported farther in the same time.

Radionuclides like ^{241}Am and ^{243}Am reach the environment when the parameter is increased to 100, even though they do not reach the accessible environment within 10,000 years with a longitudinal dispersivity of 1.

The decreased travel times from changes in longitudinal dispersivity increases the EPA ratio for some of the radionuclides (Tables 9 and 10). It is interesting to compare how the EPA ratio changes at 25 m with a longitudinal dispersivity of 1, 10, and 100 (Cases 1, 3, and 4). For ^{239}Pu, the EPA ratio with increasing dispersivity changes from 800 to 1200 and 1800, respectively. However, when the hydraulic conductivity is increased (Cases 7, 9, and 10), the EPA ratio remains about 2800 for all three values of longitudinal dispersivity. This difference is due to a high Darcy velocity and a source-term profile that is constant in time. This value is higher than all the values for the low hydraulic conductivity case.

Variations in the Darcy flux were examined by changes in the gradient. A decrease in the gradient reduced the Darcy flux and increased the travel time. This change had a pronounced effect on travel time for the retarded radionuclides. The travel time results varied as much as 1000 years. An increase in the gradient increased the Darcy flux and decreased the travel time. These results were expected because the travel time is inversely related to the gradient. The results show that the gradient can significantly alter the radionuclide travel times, and more information should be collected during the field-based site suitability studies.

CONCLUSIONS

The results from this analysis indicate that if contaminants reach the Paleozoic aquifer, they are likely to reach the accessible environment within 10,000 years. The sensitivity analysis indicates which conditions could enhance transport of the nuclides. The unretarded radionuclides reach the accessible environment under all conditions examined, while retarded radionuclides sometimes do not reach the accessible environment. The EPA ratio provides an index of the degree to which the EPA criteria could potentially be violated.

Of all the parameters examined, modeling results are most sensitive to changes in the hydraulic conductivity. This sensitivity is important because this analysis assumed only matrix flow and did not consider fracture flow. The range of conductivities used was based on an aquifer test conducted in Well UE-25p#1; this range was assumed to reflect the thickness of the unit. If the transport is actually fracture-dominated, travel times may decrease significantly from those calculated here. In further site characterization, obtaining the hydraulic conductivity and fracture characteristics of the Paleozoic aquifer is very important in understanding how flow occurs in the aquifer.

The next parameter of importance in the sensitivity analysis was the gradient of the aquifer. As indicated in the beginning of this report, there is some evidence based on wells located on the NTS that the gradient in the aquifer may actually be upward, instead of horizontal. This difference would alter the current results and most likely increase the travel time. This increase probably would not prevent the unretarded radionuclides from reaching the accessible environment, but may prevent the retarded radionuclides from reaching the accessible environment. The gradient should be characterized at several different locations.

The final parameter of interest is the longitudinal dispersivity. No field tests can provide information on this parameter. Laboratory-scale tests often do not translate well to the field scale and can lead to erroneous

information. This parameter should be used as a sensitivity analysis to test the upper bound of the system in computer modeling, but no attempt should be made quantify it in the field.

The Paleozoic aquifer is only likely to be contaminated during a human intrusion scenario (i.e., when a person is exploring for minerals). This case considered the worst case of emptying an entire waste package down the borehole. In reality, only a portion of the container would reach the aquifer, and the rest would be brought to the surface. Estimates have recently been made on the likelihood of drilling intercepting a waste container[(a)], and these should be included in the evaluation of the risk imposed by this disruptive scenario.

(a) Gallegos, D. P. 1991. Memo on Probability of Intersecting a Waste Package Based on Geometric Considerations. Sandia National Laboratory, Albuquerque, New Mexico.

REFERENCES

40 CFR 191. U.S. Environmental Protection Agency, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rules." U.S. Code of Federal Regulations.

Craig, R. W., and K. A. Johnson. 1984. Geohydrologic Data for Test Well UE-25p#1, Yucca Mountain Area, Nye County, Nevada. U.S. Geological Survey, Open-File Report 84-450, Lakewood, Colorado.

Craig, R. W., and J. H. Robison. 1984. Geohydrology of Rocks Penetrated by Test Well UE-25p#1, Yucca Mountain Area, Nye County, Nevada. U.S. Geological Survey, Water Resources Investigation 84-4248, Denver, Colorado.

Czarnecki, J. B. 1985. Simulated Effects of Increased Recharge on the Ground-Water Flow System of Yucca Mountain and Vicinity, Nevada-California. U.S. Geological Survey, Water Resources Investigation 84-4344, Denver, Colorado.

Czarnecki, J. B., and R. K. Waddell. 1984. Finite-Element Simulation of Ground-Water Flow in the Vicinity of Yucca Mountain, Nevada-California. U.S. Geological Survey, Water Resources Investigation 84-4349, Denver, Colorado.

DOE (U.S. Department of Energy). 1988. Site Characterization Plan Yucca Mountain Site, Nevada Research and Development Area, Nevada. DOE/RW-0199, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D. C.

Eslinger, P. W., and B. Sagar. 1988. EPASTAT: A Computer Model for Estimating Releases at the Accessible Environment Boundary of a High-Level Nuclear Waste Repository - Mathematical Model and Numerical Model. BWIP Supporting Document, SD-BWI-TA-022, Westinghouse Hanford Company, Richland, Washington.

Jackson, Kern C. 1970. Textbook of Lithology. McGraw-Hill, San Francisco.

Waddell, R. K. 1982. Two-Dimensional, Steady State Model of Ground-Water Flow,Nevada Test Site and Vicinity, Nevada-California. U.S. Geological Survey, Water Resources Investigation 82-4085, Denver, Colorado.

Winograd, I. J., and W. Thordarson. 1975. Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site. U.S. Geological Survey, Professional Paper 712-C, Washington, D. C.

APPENDIX A

RADIONUCLIDE RELEASE RATES

RADIONUCLIDE RELEASE RATE (CURIES/YR)								
	Groundwater inflow =		3000 m^3/yr					
	Year of failure =		500					
Year	TC 99	I129	CS135	NP237	PU239	PU240	AM241	AM243
501	0	0	0	0	0	0	0	0
502	5.226E-01	1.266E-03	1.387E-02	1.620E-04	6.167E-02	9.992E-02	3.406E-01	3.164E-03
600	2.600E-03	6.300E-06	6.900E-05	1.709E-04	6.150E-02	9.880E-02	2.939E-01	3.206E-03
700	2.600E-03	6.300E-06	6.900E-05	1.800E-04	6.133E-02	9.772E-02	2.491E-01	3.177E-03
800	2.600E-03	6.300E-06	6.900E-05	1.884E-04	6.119E-02	9.679E-02	2.155E-01	3.152E-03
900	2.600E-03	6.300E-06	6.900E-05	1.961E-04	6.106E-02	9.598E-02	1.895E-01	3.130E-03
1000	2.600E-03	6.300E-06	6.900E-05	2.017E-04	6.087E-02	9.489E-02	1.596E-01	3.099E-03
1200	2.600E-03	6.300E-06	6.900E-05	2.085E-04	6.041E-02	9.240E-02	1.066E-01	3.027E-03
1400	2.600E-03	6.300E-06	6.900E-05	2.145E-04	6.003E-02	9.033E-02	7.569E-02	2.967E-03
1600	2.600E-03	6.300E-06	6.900E-05	2.198E-04	5.969E-02	8.856E-02	5.615E-02	2.915E-03
1800	2.600E-03	6.300E-06	6.900E-05	2.246E-04	5.940E-02	8.703E-02	4.311E-02	2.870E-03
2000	2.599E-03	6.300E-06	6.900E-05	2.284E-04	5.910E-02	8.545E-02	3.265E-02	2.823E-03
2500	2.588E-03	6.300E-06	6.900E-05	2.316E-04	5.824E-02	8.074E-02	1.377E-02	2.681E-03
3000	2.579E-03	6.300E-06	6.900E-05	2.341E-04	5.750E-02	7.687E-02	6.540E-03	2.564E-03
3500	2.573E-03	6.300E-06	6.900E-05	2.347E-04	5.659E-02	7.217E-02	2.569E-03	2.426E-03
4000	2.568E-03	6.300E-06	6.900E-05	2.352E-04	5.582E-02	6.833E-02	1.141E-03	2.312E-03
4500	2.564E-03	6.300E-06	6.900E-05	2.356E-04	5.514E-02	6.510E-02	5.575E-04	2.215E-03
5000	2.559E-03	6.300E-06	6.900E-05	2.360E-04	5.449E-02	6.212E-02	2.981E-04	2.126E-03
5500	2.554E-03	6.300E-06	6.897E-05	2.360E-04	5.345E-02	5.779E-02	1.936E-04	1.993E-03
6000	2.549E-03	6.300E-06	6.894E-05	2.360E-04	5.252E-02	5.409E-02	1.305E-04	1.880E-03
6500	2.544E-03	6.300E-06	6.892E-05	2.360E-04	5.167E-02	5.090E-02	9.073E-05	1.781E-03
7000	2.540E-03	6.300E-06	6.890E-05	2.360E-04	5.090E-02	4.811E-02	6.481E-05	1.694E-03
7500	2.536E-03	6.300E-06	6.888E-05	2.360E-04	5.020E-02	4.565E-02	4.737E-05	1.617E-03
8000	2.532E-03	6.300E-06	6.886E-05	2.360E-04	4.954E-02	4.346E-02	3.533E-05	1.548E-03
8500	2.529E-03	6.300E-06	6.885E-05	2.360E-04	4.894E-02	4.149E-02	2.682E-05	1.486E-03
9000	2.526E-03	6.300E-06	6.883E-05	2.360E-04	4.838E-02	3.973E-02	2.068E-05	1.430E-03
9500	2.523E-03	6.300E-06	6.881E-05	2.360E-04	4.785E-02	3.812E-02	1.617E-05	1.378E-03
10000	2.518E-03	6.300E-06	6.880E-05	2.360E-04	4.714E-02	3.605E-02	1.289E-05	1.312E-03
Total	2.485E+01	6.117E-02	6.694E-01	2.193E+00	5.131E+02	5.909E+02	2.125E+02	2.013E+01

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