EEG-8

The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP

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Environmental Evaluation Group

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800901

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NEW MEXICO
HEALTH AND ENVIRONMENT
DEPARTMENT

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NOTICE TO THE READER

The Environmental Evaluation Group (EEG) was assigned to the New Mexico Institute of Mining and Technology in October 1988 by the National Defense Authorization Act, Fiscal Year 1989, Public Law 100-456, Section 1433, and is no longer a part of the New Mexico Health and Environment Department, Environmental Improvement Division. Continued funding is being provided by the Department of Energy through Contract DE-AC04-79AL10752.

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September, 1980
(Reprinted August, 1989)

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CONTENTS

FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the Waste Isolation Pilot Plant (WIPP), a Federal radioactive waste repository proposed for construction underground in an area near Carlsbad, New Mexico. The objective of the EEG evaluation is to protect the public health and safety and ensure that there is no environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP. Analyses are conducted by EEG of reports issued by the U.S. Department of Energy (DOE) and its contractors, other Federal agencies, and other organizations as they relate to the potential health, safety, and environmental impacts of WIPP. These analyses may involve public meetings, site visits, and consultations with agencies, professional associations, and scientific experts.

The project is funded entirely by the U.S. Department of Energy through Contract #DE-AC-04-79AL10752 with the New Mexico Health and Environment Department.

Robert H. Neill
Director

LIST OF FIGURES and TABLES

SUMMARY

This report considers some aspects of the radionuclide transport modeling presented in documents published by the U. S. Department of Energy (DOE) regarding the Waste Isolation Pilot Plant (WIPP) nuclear waste repository proposed for development in Southeastern New Mexico. The radionuclide transport modeling is used to predict worst possible consequences of a WIPP repository breach event in which waste enters groundwater. The aim of this report is to determine whether plausible changes in the parameters used by DOE to describe the flow of groundwater near the WIPP site could result in: a) significantly faster radionuclide movement in groundwater; and b) significantly higher concentrations of radionuclides in Pecos River water and correspondingly higher radiation doses than predicted by DOE. The conclusion reached is that while plausible changes in hydrologic conditions and waste-rock interactions might result in a significant reduction in the time it takes for radionuclides to reach the Pecos River, the shorter travel times do not result in significant increases in the estimated concentrations of radionuclides in the Pecos River nor in the radiation doses associated with the use of such water. Other ways in which parameter changes might affect these concentrations and doses are mentioned in the Conclusions section of the report, but are not the subject of this analysis.

The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Exposures from WIPP

I. Introduction

To estimate worst possible radiation doses which might result from a hydrologic breach of the proposed WIPP repository, the U. S. Department of Energy (DOE) has considered situations in which:

1. groundwater passes through the repository, dissolves some waste and brings the dissolved radionuclides into the Rustler aquifer;
2. the radionuclides are carried by the Rustler water to the Pecos River at Malaga Bend, fifteen miles from the WIPP site.

(See, for example, the WIPP Safety Analysis Report, Ref. 1 and the Draft Environmental Impact Statement for WIPP, Ref. 2). Figure 1 illustrates two of the breach events which have been analyzed.

The aim of this report is to assess the assumptions made in modeling step 2, nuclide transport in the Rustler. The question is: has a worst (plausible) case really been considered?

In its report of a January, 1980 meeting of geologists and hydrologists to discuss conditions in the vicinity of the WIPP site, the Environmental Evaluation Group has summarized information presented concerning the status of hydrologic testing and questions raised concerning the adequacy of the available data for predicting consequences of a repository breach(Ref. 3). It is clear that there are uncertainties in the hydrologic parameters used for modeling flow in the Rustler aquifer, and that there are even greater uncertainties involved in predicting changes in hydrologic conditions that might occur over thousands or millions of years. However, it is not clear that these uncertainties introduce equivalent uncertainties into the projected consequences of a worst case WIPP repository breach. This report will address the question of whether or not a worst plausible case has been considered in the WIPP Safety Analysis Report (SAR) nuclide transport modeling by asking:

Can plausible changes in the nuclide transport modeling assumptions and Rustler aquifer parameters result in significantly higher estimates of peak radionuclide concentrations in Pecos River water? (By "peak concentration" is meant the radionuclide concentration in Pecos River water at Malaga Bend, measured in picocuries per liter, at the time when that concentration is highest.)

In order to limit attention to step 2 of the breach event modeling, nuclide transport in the Rustler aquifer, it is assumed that radionuclides enter the Rustler at a given rate and move along a flow path to Malaga Bend. Then the calculated radionuclide concentrations in Pecos River water and the resulting radiation doses depend primarily on the transit times of the radionuclides in the Rustler, between the WIPP site and the Pecos River. For radionuclides in the initial repository inventory, the longer it takes the nuclide to reach the Pecos River, the smaller its concentration will be in the river, because of radioactive decay of the nuclide. For radioactive decay products, the situation is more complex, because ingrowth causes an increase in activity over a period of time, followed by a decrease.

This paper is organized as follows:

Section II outlines the models used in the WIPP SAR (Ref. 1) and in this report to describe radionuclide transport in the Rustler aquifer. The next two sections explore the relation between peak radionuclide concentrations in the Pecos River and key hydrologic parameters. First, Section III considers the relation between the hydrologic parameters and the radionuclide travel times. Then, Section IV considers the relation between radionuclide travel times and peak radionuclide concentrations in the Pecos River. Sections V and VI examine the plausibility of various changes in parameter values and modeling assumptions used to assess consequences of a WIPP repository breach. In Section VII, radiation dose commitments which could result from drinking Pecos River water are calculated, under a variety of assumptions. Conclusions are summarized in Section VIII.

Although this analysis investigates only a portion of the breach consequence assessment which has to do with nuclide transport in the aquifer, it is necessary to have some source term to use for radionuclide concentration and dose calculations. That is, one must start with a rate at which radionuclides are introduced into the aquifer. For illustrative purposes, this analysis will focus on a single radionuclide, Plutonium-239 (Pu-239). This choice is made for the following reasons: The waste proposed for permanent disposal at WIPP is transuranic waste, primarily that classified as contact handled.* The radionuclide content includes plutonium and americium isotopes. Pu-239 is the dominant radionuclide in contact handled transuranic waste, in the sense that it has a long half-life (2.4×10^4 years) and a higher initial inventory than any of

* Transuranic waste (i.e., waste contaminated with plutonium, americium and other radionuclides with atomic number greater than that of uranium) is classified as contact handled if its container has a surface dose rate of 200 mrem/hr or less.

the other alpha-emitting radionuclides present. However, under the hydrologic modeling assumptions used in the WIPP SAR, Pu-239 travels so slowly in the Rustler aquifer that it decays before it reaches the Pecos River. While its decay product Uranium-235 does contribute significantly to dose estimates, Plutonium-239 itself does not. This analysis will explore the possibility that plausible changes in the hydrologic modeling assumptions can result in a substantial portion of the Pu-239 inventory reaching the Pecos River.

In the WIPP SAR, the hydrologic breach event which would result in the largest amount of waste entering the Rustler aquifer is Communication Event 1, in which water flows from the Bell Canyon aquifer below the repository, through the repository and up into the Rustler aquifer (see Figure 1). Thus, peak radionuclide concentrations and dose commitments will be calculated based on the rate at which Plutonium-239 would be released into the Rustler aquifer under the SAR assumptions for Communication Event 1.

III. Nuclide Transport Model

The Sandia Waste Isolation Flow and Transport model (SWIFT), developed by Intera Environmental Consultants, Inc., has been used by the Department of Energy for calculations involving nuclide transport in the Rustler aquifer (Ref. 4). For the purposes of calculating the nuclide concentrations in Rustler brine entering the Pecos River, a simplified version of the model is used by DOE (Ref. 1, Section 8.2.1.3.3). The basic assumptions made for this application can be outlined as follows:

Assumption 1. Water Flow in the Rustler Aquifer

Water moves along a one-dimensional flow path with average velocity $\bar{v}$ given by Darcy's Law:

$$\bar{v} = \frac{K}{\theta} \cdot \frac{\Delta h}{\Delta \ell} \quad \text{ft/yr} \qquad (1)$$

where:

θ = aquifer porosity

K = hydraulic conductivity or permeability (ft/yr)

$\frac{\Delta h}{\Delta \ell}$ = hydraulic gradient (change in hydraulic head per unit distance).

To account for the fact that at any time and position, some water particles are moving more rapidly than the average while some are moving more slowly, the differential equation describing flow includes a term which reflects this "longitudinal dispersivity."

Assumption 2. Equilibrium Adsorption of Nuclides

At any point in the aquifer and at any time, the activity concentration of a given radionuclide is distributed between the aquifer rock and the aquifer water as follows:

$$C_s = K_d \, C_L \qquad (2)$$

where:

C_s = activity concentration in/on rock (pCi/g)

C_L = activity concentration in water (pCi/mℓ)

K_d = distribution coefficient for the nuclide in question (mℓ/g).

Assumption 3. Radioactive Decay and Ingrowth

Nuclide concentrations change with time because of radioactive decay. These changes are built into the SWIFT model.

In order to study the effects of parameter changes on nuclide concentration and dose estimates, it is useful to simplify Assumption 1 still further and neglect longitudinal dispersivity. This can be justified only if the simplification does not change the model predictions significantly, for the nuclides under consideration. In Appendix VI of Ref. 5, Greenfield has shown that for long-lived radionuclides and their decay products this is indeed the case; that is, the peak concentration and dose estimates obtained using the SWIFT model, including longitudinal dispersivity, are close to those obtained using the analogous model with zero dispersivity. Results of the two models differ by less than a factor of 2 in the case of long-lived initial inventory radionuclides. When additional approximations are made in connection with the simple model to accommodate a decay chain in which different members move with different velocities, the concentration and dose estimates obtained from the two models still differ by less than a factor of 5. Peak concentration and dose estimates obtained using the simpler model tend to be larger than those obtained taking dispersivity into account.

Thus, for the remainder of this analysis, the following assumption will be made.

Assumption 4. Zero Dispersivity

Longitudinal dispersivity is zero. All water particles move with the average velocity $\bar{v}$ given by equation (1).

Under these assumptions, it can be shown (Ref. 5, Appendix VI) that a nuclide with a distribution coefficient K_d (mℓ/g) will move in the aquifer with velocity:

$$r = \frac{\bar{v}}{B} \quad \text{ft/yr} \qquad (3)$$

where B, the retardation factor, is given by:

$$B = 1 + \frac{\rho}{\theta} K_d \qquad (4)$$

ρ = aquifer density (g/mℓ).

III. Hydrologic Parameters and Nuclide Travel Times

Suppose the aquifer parameters defined in Section II are constant over a portion of the flow path which is d feet long. Then the time T that it takes for a nuclide to travel through that part of the flow path is given by:

$$T = \frac{d}{r} = \quad yr \qquad (5)$$

where r is the nuclide velocity, given in ft/yr.

Combining equations (1), (3), (4) and (5) gives:

$$T = \frac{d(\theta + \rho K_d)}{K\ (\Delta h/\Delta \ell)} \quad yr \qquad (6)$$

for the time T that it takes for a radionuclide with distribution coefficient K_d to traverse a segment of the aquifer having length d, porosity θ, density ρ, hydraulic conductivity K and hydraulic gradiant $\Delta h/\Delta \ell$.

To illustrate the effects of the various parameters on T, consider Plutonium-239 traversing the first 5 miles of the flow path from the repository to the Pecos River. The parameter values for this interval, based on information in the SAR*, are:

$$d = (5\ mi)\ (5280\ ft/mi) = 2.6 \times 10^4\ ft$$

$$\theta = 0.1$$

$$\rho = 2\ g/m\ell$$

$$K_d = 2.4 \times 10^3\ m\ell/g$$

$$K = 1\ ft/day\ or\ 365\ ft/yr$$

$$\frac{\Delta h}{\Delta \ell} = \frac{100\ ft}{(5\ mi)\ (5280\ ft/mi)} = 3.8 \times 10^{-3}.$$

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* Table 3.3-1 gives $\theta = 0.1$; Table 2.5-12 gives 2.4×10^3 mℓ/g as the lowest K_d value measured with plutonium, groundwater and Rustler formation rock; Figure 8A-4 gives K=1 ft/day at the WIPP site (Ref. 1).

The hydraulic gradient $\Delta h/\Delta \ell$ is computed on the basis of the potential lines shown in Figure 2. Over the first 5 miles of the flow path from the repository, the calculated hydraulic potentials in the Rustler aquifer drop 100 feet, from about 3150 to 3050 feet.

Substituting these parameter values into equation (6) one finds that the time T that it would take for Pu-239 to migrate over this 5 mile stretch is:

$$T = 9.0 \times 10^7 \text{ yr.}$$

The question is: What changes in parameter values could reduce the travel time T significantly? To make the example more specific, what changes in parameter values could result in an order of magnitude decrease in T?

If the distribution coefficient K_d decreases by an order of magnitude, the travel time T decreases by an order of magnitude. The same decrease in T would result from an order of magnitude increase in hydraulic conductivity K or hydraulic gradient $\Delta h/\Delta \ell$. Changes in the aquifer porosity θ have virtually no effect on the travel time T, provided that the distribution coefficient K_d remains high (say, above 10).

IV. Plutonium-239 Travel Time and Its Peak Concentration in the Pecos River

If Pu-239 enters the Rustler aquifer at a rate of q pCi/sec at the WIPP site, moves in the Rustler according to the assumptions in Section II, and begins to enter the Pecos River at an arrival time T_A years after waste emplacement, then the peak concentration C of Pu-239 in Pecos River water is given by:

$$C = \frac{q\ e^{-(\ell n\ 2)(T_A)/(2.4 \times 10^4)}}{F} \quad p\ Ci/\ell \qquad (7)$$

where 2.4×10^4 years is the half-life of Pu-239 and F ℓ/sec is the Pecos River flow at Malaga Bend. The minimum value for F is given in the SAR as 18 ft^3/sec (Ref. 1, 8.2-9). That is:

$$F = 5.1 \times 10^2 \ \ell/sec.$$

As discussed in Section I, the breach event under consideration in this analysis involved a hydrologic connection between aquifers above and below the repository. The SAR describes such a breach event: Communication Event 1. Under the SAR assumptions* for Communication Event 1, the rate q at which Pu-239 in contact handled transuranic waste enters the Rustler is:

$$q = 2.1 \times 10^4 \ \ pCi/sec.$$

Thus, from equation (7), the peak concentration C of Pu-239 in Pecos River water is:

$$C = 41 \times e^{-(\ell n2)T_A/2.4 \times 10^4} \quad pCi/\ell \qquad (8)$$

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* The steady state repository dissolution rate is given as 0.25 ft^3/day (p. 8.3-5); the fraction of the repository volume which is waste is 0.115 (p. 8.3-3); and the specific activity of Pu-239 in the waste is 2.21×10^{-3} Ci/ℓ (Table 3.1-2). Then q = (0.25 ft^3/day) x (0.115) x (28.32 ℓ/ft^3) x (2.21×10^{-3} Ci/ℓ) x 10^{12} pCi/Ci) ÷ (8.64×10^4 sec/day), (Ref.1).

where the arrival time T_A is the sum of the breach time (i.e. the number of years between waste emplacement and the repository breach event) and the Pu-239 travel time (i.e. the time it takes for Pu-239 to travel in the Rustler aquifer from the WIPP site to the Pecos River).

Using the information in the SAR concerning Rustler aquifer hydrology and distribution coefficients*, the time between a breach event and the arrival time of Pu-239 at the Pecos River would be about 1.4×10^8 years.**

The Pu-239 in the repository inventory would decay in this time, since Pu-239 has a half-life of 2.4×10^4 years. However, this analysis considers whether plausible changes in parameters can lead to significantly shorter travel times and significantly higher radiation doses than those derived from the parameters used in the SAR analysis. For the moment, equation (8) will be used to study the dependence of the peak Pu-239 concentration C on the arrival time T_A, without regard to the plausibility of different T_A values. The plausibility of different arrival time values will be discussed in Section V.

Figure 3 illustrates the relation between the peak Pu-239 concentration C in Pecos River water and the Pu-239 arrival time T_A. Using equation (8), C is plotted against the logarithm of T_A. This semi-log plot makes it easy to see how order-of-magnitude changes in T_A affect C. Table 1 summarized key values of C.

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* Table 2.5-12, Table 8.3-1, Figure 8A-2 and Figure 8A-4, (Ref. 1).

** The sum of the travel times for the first 5 miles, where K=1 ft/day and the last 10 miles, where K=4 ft/day (Ref. 1, Figure 8A-4). The other parameters are as given in Section III.

It can be seen from Figure 3 and Table 1, that arrival times between 0 and 10,000 years all result in roughly the same peak Pu-239 concentrations in the Pecos River. If the Pu-239 starts to enter the Pecos River 100,000 years after waste emplacement, then the peak concentration is less than a tenth of what it would be if the arrival time were 10,000 years. An arrival time of 500,000 years results in a further reduction of the peak Pu-239 concentration by a factor of 10^{-5}.

This suggests a way of making the basic question more precise:

1. Can plausible changes in the modeling assumptions or hydrologic parameters used in the WIPP SAR analysis result in a Pu-239 Pecos River arrival time of less than 100,000 years?
2. Can the Pu-239 arrival time be less than 10,000 years?

V. The Validity of Using Average Parameter Values

As discussed in Section III, an order of magnitude decrease in distribution coefficient (K_d) or increase in hydraulic conductivity (K) or hydraulic gradient ($\Delta h/\Delta \ell$) would result in an order of magnitude decrease in the travel time (T). Parameter changes amounting to more than three or four orders of magnitude would be necessary to reduce the travel time from 14,000,000 years to 100,000 or 10,000 years. The next step, then, in this analysis, is to evaluate the potential for large changes in the three key parameters.

The hydraulic gradient $\Delta h/\Delta \ell$ appears to be the least variable of these parameters. In order for the average hydraulic gradient to increase by a factor of 10, the difference between potentiometric levels of the Rustler at the WIPP site and at the Pecos River would have to go from 300 to 3000 feet. Such a change does not appear credible.

The hydraulic conductivities K for different portions of the flow path are more likely to deviate from the assumed values, either because of difficulties in measurement, non-uniformity of the aquifer or future changes (e.g. fracturing of the aquifer rock or dissolution of salt in the Rustler at the WIPP site). The SAR calculations of hydraulic conductivities in the Rustler show an increase from 1 ft/day near the WIPP site to 64 ft/day at the Pecos River. It does not appear likely that hydrologic conditions in the vicinity of the site would change so drastically in 10,000 or even 100,000 years that they would match present conditions in the Rustler near the Pecos River. Perhaps an increase by one order of magnitude in hydraulic conductivity values can be taken as a worst plausible case.

The most unpredictable of the parameters is the distribution coefficient (K_d). Laboratory K_d measurements using apparently identical rocks, solutions and precedures can differ by an order of magnitude. Changing the rock or solution slightly can result in greater discrepancies. Different laboratories report widely different results (e.g. plutonium K_d values between 16 and 20 mℓ/g for Culebra dolomite and "prepared water" in Ref. 6 and values of 2,100 mℓ/g for Culebra dolomite and brine and 7,300 mℓ/g for Culebra dolomite and groundwater in Ref. 7). In addition to the problems just discussed involving reproducibility of laboratory measurements, there are problems involved with predicting and studying in-situ conditions. Many factors influence the relative amounts of a nuclide in the solid and liquid phases of an aquifer. For example, the concentration of the nuclide in question or of other elements, can affect the capacity of the rock to absorb more of the radionuclide; thus a "loading effect" can reduce K values. Chelating agents like EDTA can also reduce K_d values, as can temperature, pH and other physical and chemical properties of the rock, the water and the nuclide. Table 21 in Ref. 7 shows a reduction of one to two orders of magnitude in K_d (for Gd-153, Eu-152 and Ce-144) when a plywood extract is added to the solution.

Therefore, it is conceivable that average K_d values for nuclides in a waste and brine mixture, moving through fifteen miles of the Rustler aquifer, would turn out to be two or even three orders of magnitude smaller (or larger) than the value used in the WIPP SAR nuclide transport modeling. However, statements in the SAR indicate that the K_d values chosen already reflect a worst case (i.e. lowest plausible average values).

The plutonium K_d value used in the SAR modeling is the lower of two K_d values reported in WIPP site-specific tests using simulated groundwater and Rustler formation rock from just outside the WIPP boundary (Ref. 1, Table 2.5-12). Further, the measurements are made using a highly oxidized species of plutonium, which is thought to be more mobile than species with lower oxidation states but less likely to be present following a repository breach (Ref. 1, p.2.5-43).

VI. Heterogeneity of Aquifer and Nuclide Properties

The preceding section considered the extent to which the average values of key parameters could differ, now or in the future, from those used in the WIPP safety assessment. This section will discuss the extent to which it is appropriate to look at average behavior. The answer proposed is in two parts.

1. In this application, it is appropriate to use average hydrologic parameters to describe water movement in the aquifer.
2. The use of a single average distribution coefficient for each nuclide may mask significant effects resulting from the migration of a subpopulation of the nuclide particles.

Point 1, regarding water movement in the aquifer, requires some qualification. The claim is that it is appropriate to use average parameter values over intervals where there are no large scale changes in hydrologic conditions. For example, one should not lump mile-long stretches where the hydraulic conductivity is measured as 1 ft/yr with mile-long stretches where the hydraulic conductivity is measured as 50 ft/yr. However, small scale variations should not add up to gross effects on water movement over a 15 mile flow path. In its travel from the WIPP site to the Pecos River, each water drop will pass through 1 inch or 10 foot fractures where it moves relatively quickly and through small portions of the aquifer which are less permeable than the average. The hydraulic gradient may be steep over a small interval, but will be less steep than the average somewhere else. This type of variation over short intervals would not result in significant changes in the nuclide concentrations and doses calculated on the basis of average values of hydrologic parameters over several mile intervals.

What is the difference, then, between the use of average aquifer parameters and the use of average distribution coefficients? The difference, as suggested in point 2, is that there may be subpopulations of nuclide particles which migrate through the whole 15 mile flow path in a way that differs significantly from the predicted norm.

Consider the case of plutonium. Under the equilibrium adsorption assumption stated in Section II, using a K_d value of 2400 mℓ/g, each plutonium particle spends a large amount of time associated with the aquifer rock and not moving with the water. This is what slows the plutonium down in its migration through the aquifer. Since there is a single K_d value governing the behavior of all of the particles, all are slowed down equally.

It is more likely, especially given the heterogeneity of the contact handled transuranic waste to be stored in the WIPP repository, that plutonium and other radionuclides will be in various physical and chemical states and complexes and will be heterogeneous in their affinity for aquifer rock and their solubility in water.

Two lines of experimental evidence suggest that if a repository breach occurred, a fraction of the plutonium particles entering the Rustler would move with an effective distribution coefficient of zero. In the plywood extract experiment discussed in Section V, there is an apparently lowering of K_d when the organic material is added to the brine-rock-nuclide mixture used to measure K_d. One interpretation suggested in Ref. 7 is that some of the nuclide particles are in organic complexes. The reason this would lower the apparent K_d is that the particles in organic complexes would remain in solution (i.e. behave as if their K_d were zero) while the other particles would not change their behavior.

In these batch experiments, movement is not observed and the chemical forms of nuclides and nuclide complexes are not determined, so any heterogeneity in form or behavior of the nuclide in question would not be observed directly.

Column infiltration experiments reported in Ref. 6 provide direct evidence of transuranic nuclide fractions which move in water through porous rock columns at the speed of water (i.e. with $K_d = 0$).* Additional amounts of the nuclide are observed to travel more slowly than water in the columns but much more rapidly than would be predicted on the basis of average K_d values measured in either batch or column experiments.**

It is not clear how to apply the results of these column infiltration experiments to nuclide migration modeling in the case of a repository breach event. The experiments discussed in Ref. 6 were not done with Rustler formation rocks. In addition, the nuclides were not in solution with organic material or minerals which would be present in the event of a WIPP repository breach. Finally, nuclide migration behavior over a distance of several centimeters in a column may not mimic nuclide behavior over a fifteen mile path. However, until WIPP-specific experiments or theoretical analyses are performed which rule out the presence of a mobile plutonium (or transuranic) fraction under WIPP conditions, this possibility should be included in the

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* The fractions listed are 7×10^{-5} for Pu^{4+} in limestone; 3×10^{-4} for Np^{5+} in limestone; and 1.3×10^{-2} for Np^{5+} in sandstone (Ref. 6, p. 15).

** For example, in one experiment, 1/1000th of the plutonium used was observed to pass through limestone at a velocity at least equal to ½ the water velocity. A neptunium fraction of 0.12 was observed to move through sandstone at a velocity at least equal to 0.1 times the water velocity (Ref. 6, p. 15).

breach consequence assessment for WIPP. Based on the evidence available so far, it is possible that a portion of the transuranic inventory injected into the Rustler aquifer in the event of a WIPP repository breach would be in a chemical form which would allow it to move through the aquifer unretarded.

The fraction chosen to represent a plausible worst case for the remainder of this analysis is 0.01. That is, this analysis will investigate the consequences of assuming that one percent of the Pu-239 entering the Rustler aquifer in the case of a repository breach moves throughout the fifteen mile flow path at the velocity of the aquifer water. The one percent value is much higher than that observed in the Ref. 6 plutonium/limestone experiment and slightly lower than that observed in the neptunium/sandstone experiment. It is considered to be a plausible worst case value because of the conflicting influences of the presence of organic material (which might create a mobile subpopulation) and the length of the flow path (which allows time for the alteration of chemical form, breaking down subpopulations).

VII. Potential Doses from Drinking Pecos River Water

The WIPP SAR includes calculations of radiation doses which people could receive if Pecos River water were to be contaminated following a repository breach event. The doses calculated are from the ingestion of fish and water and from external exposure during swimming, boating and other activities (Ref. 1, p. 8.2-9). The largest doses are from the ingestion of water, except in the case of Radium-226 where the ingestion of fish leads to slightly greater doses than the ingestion of water. Thus dose projections based on drinking Pecos River water can give a good idea of the overall radiation dose which might be received from the various water uses.

The doses calculated in this section will be whole body fifty year dose commitments received by maximally exposed adults from one year's ingestion of Pu-239 in Pecos River water. These are the doses most easily compared with doses listed in the SAR. The dose commitment D (mrem) resulting from one year's ingestion of water with a Pu-239 concentration of C (pCi/ℓ) is given by:

$$D = (C \text{ pCi}/\ell)(730\ell)(1.9 \times 10^{-5} \text{ mrem/pCi}) \quad (9)$$

where 730 liters is the value recommended in NUREG 1.109 (Ref. 8, Table E-5) as the annual water uptake value to assume for maximally exposed adults and 1.9×10^{-5} mrem is given in NUREG 0172 (Ref. 9, Table 4) as the fifty year total body dose commitment an adult receives from ingesting 1 pCi of Pu-239 in the first year.

Table 2 lists peak Pu-239 concentrations C in Pecos River water and corresponding fifty year total body dose commitments D received by adults drinking 730 liters of the water in a year, for a variety of modifications of the SAR hydrologic modeling assumptions. Figure 4 shows how the dose commitment depends on the average K_d value used, if other parameters and assumptions are as in the SAR. The breach event is assumed to occur 1000 years after waste emplacement.

VIII. Conclusions

Based on the discussion of average parameter values in Section V, it is possible but unlikely that in the event of a hydrologic breach of the WIPP repository, the average values of the key hydrologic transport parameters would differ by more than three orders of magnitude from those used in the SAR modeling, all in a direction which would reduce the Pu-239 travel time to 100,000 years and raise the peak Pu-239 concentration in Pecos River water to 2.3 pCi/ℓ. It is very unlikely that the average Pu-239 travel time would actually be as low as 10,000 years, raising the peak Pecos River concentration to 31 pCi/ℓ.

It is possible, as discussed in Section VI, that a portion of the transuranic nuclide inventory, including Pu-239, will be in a chemical form which allows it to stay in solution and move at the velocity of the aquifer water. If one percent of the Pu-239 entering the Rustler aquifer under the conditions discussed in this analysis were to move throughout the fifteen mile flow path unretarded, this would result in a peak Pu-239 concentration in Pecos River water of 0.37 pCi/ℓ.

The fifty year total body dose commitments which adults drinking 730 liters of Pecos River water in a year would receive from the Pu-239 in the water are:

1. 3.2×10^{-2} mrem, if the Pu-239 travel time in the Rustler aquifer is 100,000 years;
2. 5.1×10^{-3} mrem, if 1% of the Pu-239 in the aquifer has a distribution coefficient (K_d) of zero.

These doses are comparable to the Radium-226 drinking water dose of 3.8×10^{-3} mrem from one year's intake, reported in

SAR Table 8.3-2. Thus, plausible variations in the SAR assumptions governing nuclide transport in the Rustler aquifer do not result in Pu-239 doses which are significantly greater than the Ra-226 doses already projected on the basis of the SAR assumptions. It can also be shown, using the methods of Greenfield in Appendix VI of Ref. 5 that the peak Ra-226 concentrations and doses do not change significantly* under plausible variations in the SAR assumptions.

This analysis addressed a limited question, and the conclusions are limited accordingly. Only part of the breach consequence analysis was considered: the modeling of nuclide transport in the Rustler aquifer. The question asked was essentially: if radionuclides were to enter the Rustler aquifer as described in the SAR breach event modeling, could plausible changes in the SAR nuclide transport modeling lead to predictions of shorter nuclide travel times and greater concentrations of radionuclides in Pecos River water than would be calculated on the basis of the SAR assumptions? The answer is that while plausible changes in hydrologic conditions and waste-rock interactions might result in significantly shortened nuclide travel time in the Rustler aquifer, the shorter times do not result in significant increases in the estimated concentrations of radionuclides in the Pecos River or in the radiation doses received by people drinking the water.

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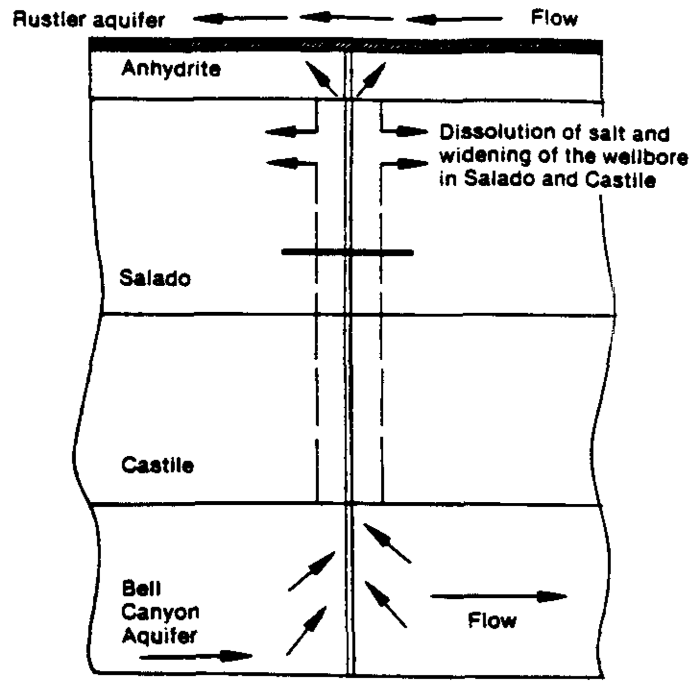
* Doses based on faster water flow in the aquifer, lower K_d's or a portion of the Ra-226 and its parent nuclides traveling with a $K_d = 0$, within limits judged in this paper as plausible, are at most 20 percent higher than those doses calculated based on SAR assumptions. If all of the Ra-226 and its parent nuclides move with a $K_d = 0$, a situation considered unlikely, then the peak Ra-226 concentration in Pecos River water would be about 7×10^{-4} pCi/ℓ and the resulting drinking water dose would be 0.1 mrem (50 year whole body commitment to a maximally exposed adult).

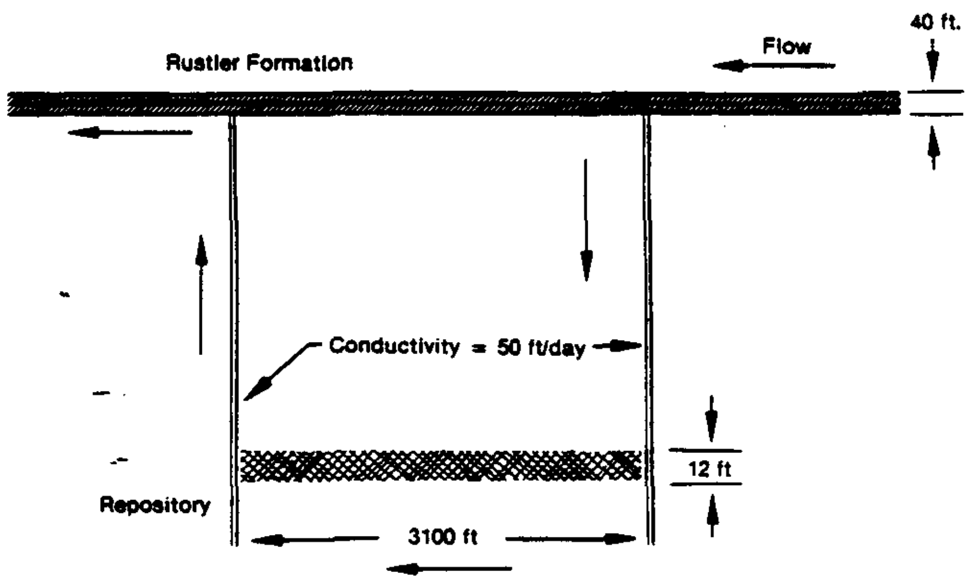
However, aquifer parameters also affect the initial stage of breach consequence analysis, which was not a part of this evaluation. For the breach event considered, in which water flows from the Bell Canyon aquifer below the repository, through the repository and into the Rustler aquifer above the repository the aquifer parameters determine the amount of water flowing through the repository and hence determine the amount of waste dissolved. If the Rustler flow increases, so will the amount of waste entering the Rustler. The relation between the hydrologic parameters and the waste dissolution rate is a subject for further study.

The radiation doses calculated in this study are a function, of course, of the repository inventory. They are low in part because the waste proposed for permanent disposal at WIPP is primarily contact handled transuranic waste. If the repository inventory is changed to include high-level waste, new dose calculations will obviously have to be performed. The methods in this paper can be used to estimate doses from any long-lived radionuclide but because of the zero dispersivity assumption, these methods might be inappropriate for estimating doses from short-lived nuclides.

For short-lived radionuclides, doses would be received primarily from the portion of the inventory moving faster than the average in groundwater.

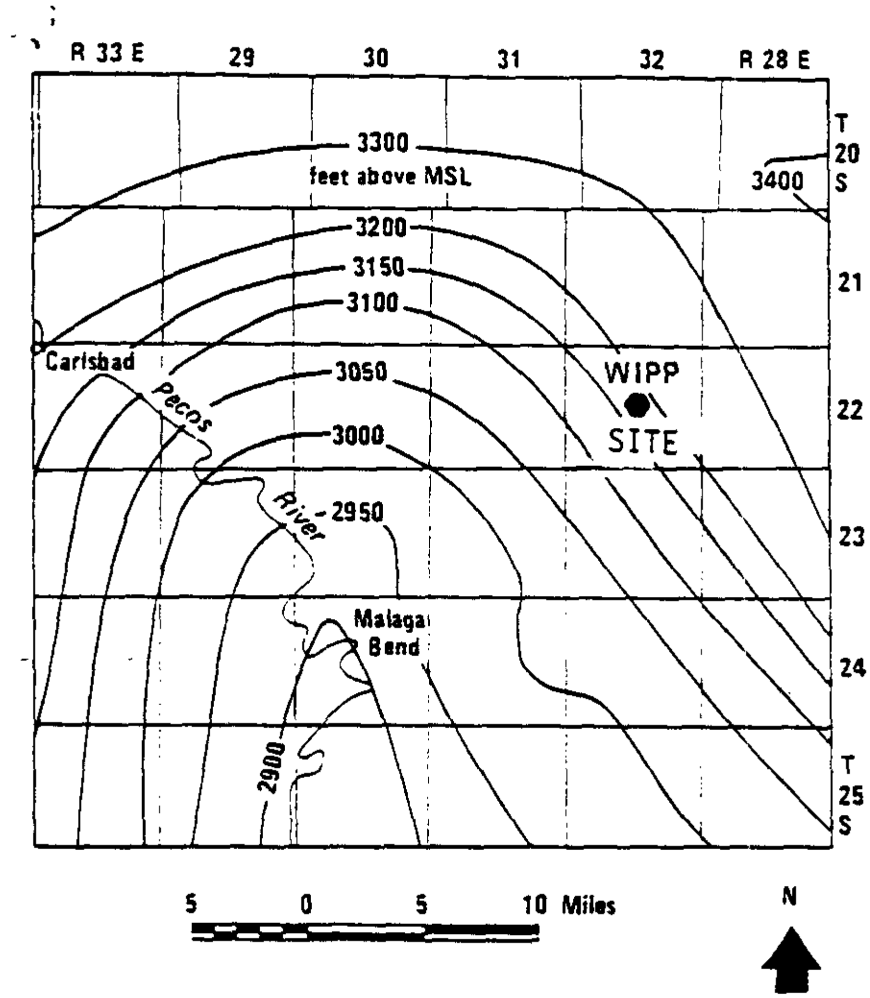


Communication Event 1



Communication Event 2

Figure 1. Schematic Diagram of Two Breach Events, Modified From WIPP DEIS Figures 9-10 and 9-11 (Ref. 2).



NOTES:

1. DATUM IS MEAN SEA LEVEL: VALUES GIVEN IN FEET — FRESH WATER (EQUIVALENT).
2. "RUSTLER AQUIFER" REFERS TO COMBINED CULEBRA AND MAGENTA AQUIFERS.

Figure 2. Reproduced from Figure 8A-2, SAR: Calculated Hydrologic Potentials in the Rustler Aquifer (Ref. 1).

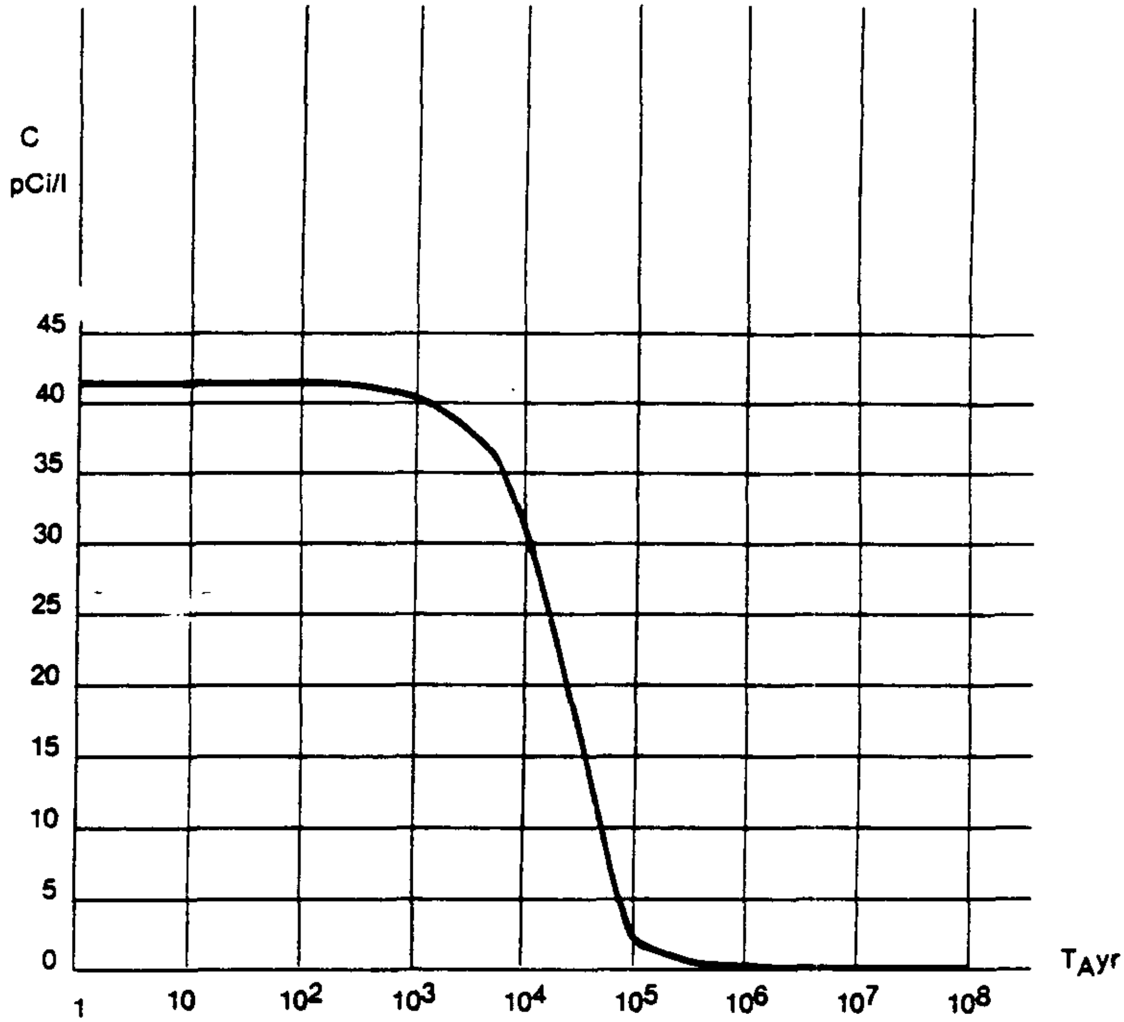


Figure 3. Peak Concentration of Pu-239 in the Pecos River as a Function of Arrival Time T_A.

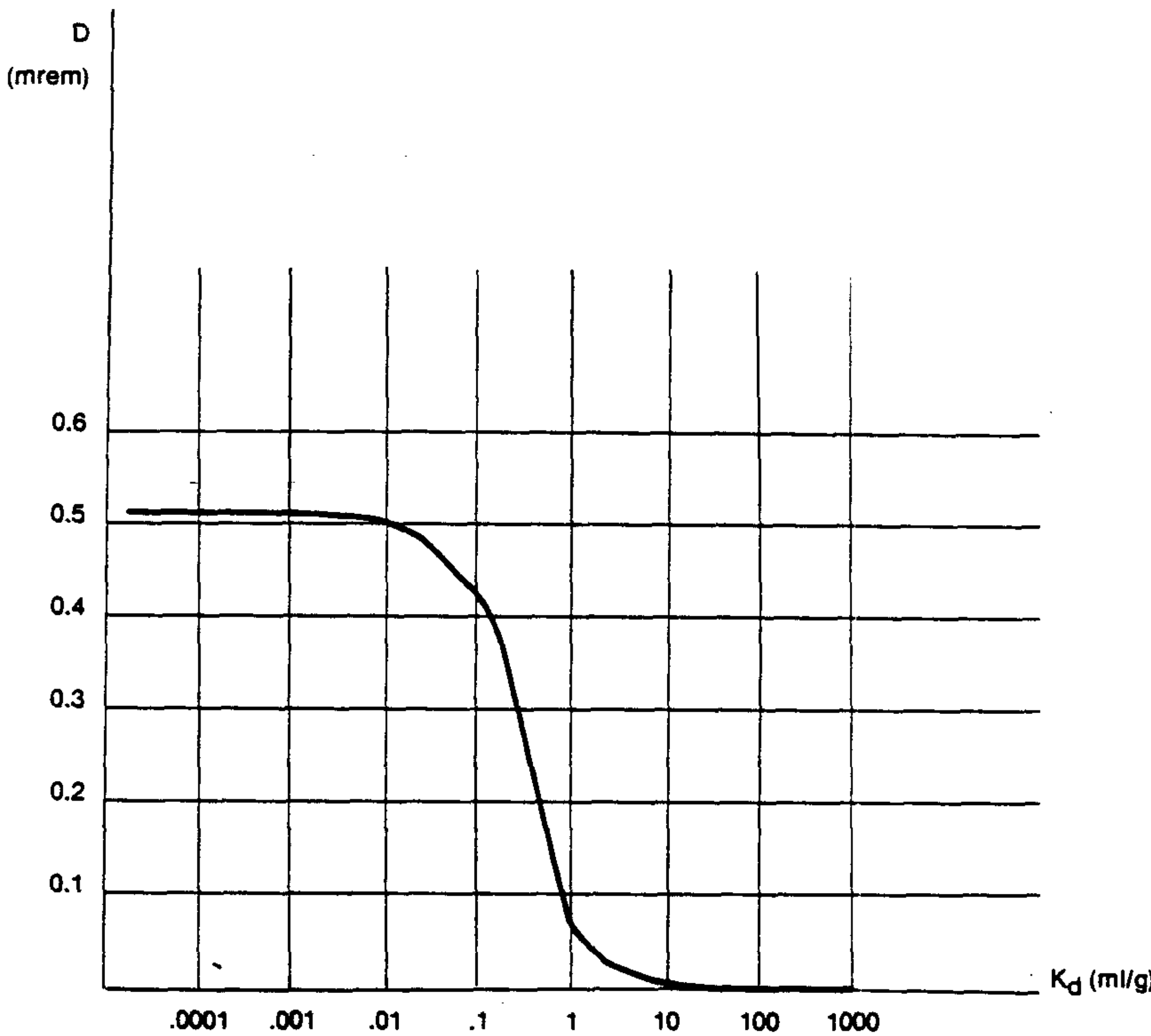


Figure 4. Fifty Year Total Body Dose Commitment D from Drinking 730 Liters of Pecos River Water in First Year, as a Function of Distribution Coefficient K_d.
(Breach time = 1000 yr.).

Table 1. Peak Pu-239 Concentration

As a Function of Arrival Time

T_A (yr)		C (pCi/ℓ)	
0		41	
1		41	
10		41	
1	+2[1]	41	
1	+3	40	
5	+3	35	
1	+4	31	
2.4	+4[2]	20.5	
3.5	+4[3]	15	
5	+4	9.7	
1	+5	2.3	
5	+5	2.2	-5
1	+6	1.2	-11
1	+7	< 1	-99
1	+8	< 1	-99

[1] 1 +2 means 10^2.

[2] Pu-239 half-life.

[3] Pu-239 mean life.

Table 2. Peak Pu-239 Concentrations and Dose Commitments

	Modification of SAR Assumptions [1]	Peak Pu-239 Concentration in Pecos River Water [2] (pCi/1)	Adult Total Body 50-Year Dose Commitment from Drinking Water [3] (mrem)
1.	None	0 [4]	0
2.	Porosity θ= 0.01	0	0
3.	Hydraulic conductivity K = 10 ft/day throughout flow path	0	0
4.	K = 50 ft/day throughout flow path (*)	0	0
5.	Distribution coefficient K_d= 100 mℓ/g throughout flow path	0	0
6.	K = 10 ft/day and K_d = 100 mℓ/g throughout flow path	1.9 -13	2.7 -15
7.	K_d = 10 mℓ/g throughout flow path	2.6 -6	3.6 -8
8.	K = 10 ft/day and K_d = 10 mℓ/g throughout flow path	1.7	2.4 -2
9.	K_d = 1 mℓ/g throughout flow path (*)	7.0	9.8 -2
10.	K_d = 0 mℓ/g throughout flow path (*)	37.	5.1 -1
11.	1% of the Pu-239 moves at the velocity of water	0.37	5.1 -3
12.	10% of the Pu-239 moves at 0.1 times the velocity of water	1.7	2.4 -2
13.	10% of the Pu-239 moves at the velocity of water (*)	3.7	5.1 -2

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(1) All modifications lead to faster nuclide movement.

(2) Based on equations (6) and (8).

(3) Based on equation (9).

(4) 0 means < 10^{-50}.

(*) Starred modifications are not considered plausible.

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8. U.S. Nuclear Regulatory Commission. *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I*. (NUREG 1.109, Revision 1), October 1977.

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