EEG-9

An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach

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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 as well as reviews 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.

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Robert H. Neill
Director

LIST OF FIGURES

AND

TABLES

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SUMMARY

As part of the assessment of the potential radiological consequences of the proposed Waste Isolation Pilot Plant (WIPP), this report evaluates the post-closure radiation dose commitments associated with a possible breach event which involves dissolution of the repository by groundwaters and subsequent transport of the nuclear waste through an aquifer to a well assumed to exist at a point 3 miles downstream from the repository.

The concentrations of uranium and plutonium isotopes at the well are based on the nuclear waste inventory presently proposed for WIPP and basic assumptions concerning the transport of waste as well as treatment to reduce the salinity of the water. The concentrations of U-233, Pu-239, and Pu-240, all radionuclides originally emplaced as waste in the repository, would exceed current EPA drinking water limits. The concentrations of U-234, U-235, and U-236, all decay products of plutonium isotopes originally emplaced as waste, would be well below current EPA drinking water limits. The 50-year dose commitments from one year of drinking treated water contaminated with U-233 or Pu-239 and Pu-240 were found to be comparable to a one year dose from natural background. The 50-year dose commitments from one year of drinking milk would be no more than about 1/5 the dose obtained from ingestion of treated water.

These doses are considered upper bounds because of several very conservative assumptions which are discussed in the report.

I. Introduction

As part of the assessment of radiation risk associated with the proposed Waste Isolation Pilot Plant (WIPP), the Department of Energy (DOE) has considered ways in which the repository might be breached long after it is sealed. Four representative scenarios chosen for analysis (Refs. 1, 2) have the following assumptions:

1) A hydrologic breach event occurs.

2) Radioactivity is leached from the waste at the same rate as salt is dissolved into water. The contaminated water is transported to the Rustler aquifer formation through a connection.

3) The contaminated water enters the Rustler aquifer and moves with the aquifer water toward Malaga Bend, where it enters the Pecos River.

The transport of radioactive waste in the Rustler aquifer is considered by DOE to be the principal pathway which would result in radioactivity entering usable water in the shortest time and in the highest concentration.

II. Statement of Problem

This report considers the following scenario:

1) Saturated brine containing leached radioactivity from the repository enters the Rustler aquifer formation.

2) Radioactive brine is transported to a well assumed to exist at a point 3 miles downstream from the repository.

3) As the brine plume moves toward the well, it is diluted such that when the water reaches the well it is assumed to be usable for agriculture, without treatment, and for drinking, after treatment to remove most of the salts.

The dose commitment to average members of the public are based on the consumption of treated well water and of milk from cows drinking untreated well water. The quantity of well water was considered insufficient for use on crops, or for other agriculture; therefore, meat and vegetable pathways were not considered. The vegetable and meat pathways would probably result in only a small fraction of the water and milk pathway.

III. Method of Calculation

The calculations are based on the model illustrated in Figure 1. The repository is separated from the biosphere by a number of barriers which must be breached sequentially if radioactivity is to reach the biosphere. The penetration of a barrier can be achieved only at a cost that is expressed quantitatively in terms of a dilution factor, i.e., radioactive water can only be carried across a barrier by mechanisms which bring about a dilution of the radioactive concentration. Under the assumption that all barriers are breached, the concentration of radioactivity of water reaching the biosphere is given by

$$C_{b,i} = (1.0E+12)(D_n \ldots D_2 D_1) C_{r,i} \qquad (1)$$

where:

$C_{b,i}$ = Concentration of radionuclide i in water that reaches the biosphere, pCi/ℓ

$C_{r,i}$ = Concentration of radionuclide i in the repository Ci/ℓ

D_j = Dilution factor associated with the breaching of barrier j

1.0E+12* = Conversion factor, Ci to pCi

The dose commitment is then calculated by

$$H_{50,i} = C_{b,i} \; U \; DCF_i \qquad (2)$$

*1.0E+12 + 1×10^{12}

$H_{50,i}$ = 50 year dose commitment for a one year intake of isotope i, mrem

U = the usage; the usage rate or consumption rate of contaminated water or milk, ℓ/yr

DCF_i = the 50 year dose commitment factor (Ref. 3), mrem/pCi

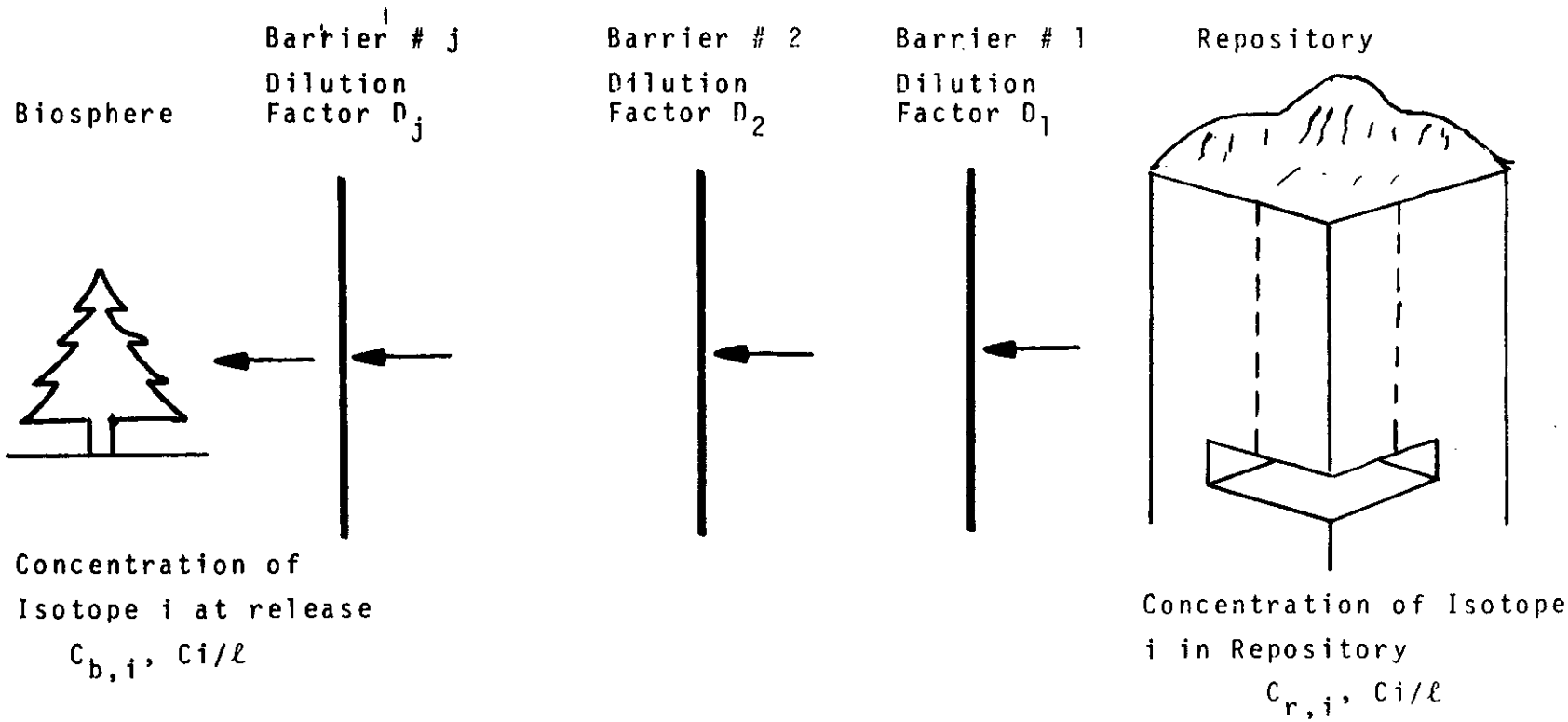

Figure 1. Schemetic of waste movement following a repository breach.

IV. Dilution Factors

1) Leaching of radioactivity from the repository by brine, D_1.

The hydrologic breach event considered is described as communication event 2 by DOE (Ref. 1, 2). Two wellbore connections are made between the Rustler formation and the repository as illustrated in Figure 2. The breach occurs 1,000 years after waste emplacement and decommissioning. Water from the Rustler aquifer flows down the upstream wellbore, through the repository, and then back to the Rustler via the downstream wellbore. Salt is continuously dissolved along the path of flow until the water becomes saturated brine. It is assumed that water leaves the Rustler with a total-dissolved-solids (TDS) concentration of 3000 milligrams per liter and reenters as saturated brine containing 410,000 milligrams per liter of TDS.* Since the density of salt is about 2, one liter of water will dissolve about 0.2 liter of salt when becoming saturated brine. It is further assumed that salt dissolution occurs uniformly along the 5500 foot flow path through the salt bed (see Figure 2) and that the leach rate of waste is equal to the leach rate of salt. The dilution factor to leach the salt/waste is then given by

$$D_1 = f_1 \, f_2 \, f_3 = 1.3E\text{-}02^* \qquad (3)$$

where:

f_1 = Volume of Salado formation dissolved per unit volume of Rustler water = 0.20

f_2 = fraction of breach path through repository = 3100/5500

f_3 = fraction of repository volume which is CH-TRU waste = 0.115

*The TDS concentration of 3000 is based upon a similar value in a well found at the James Ranch, about 3 miles from the center of the WIPP site (Reference 1, Table 7-19).

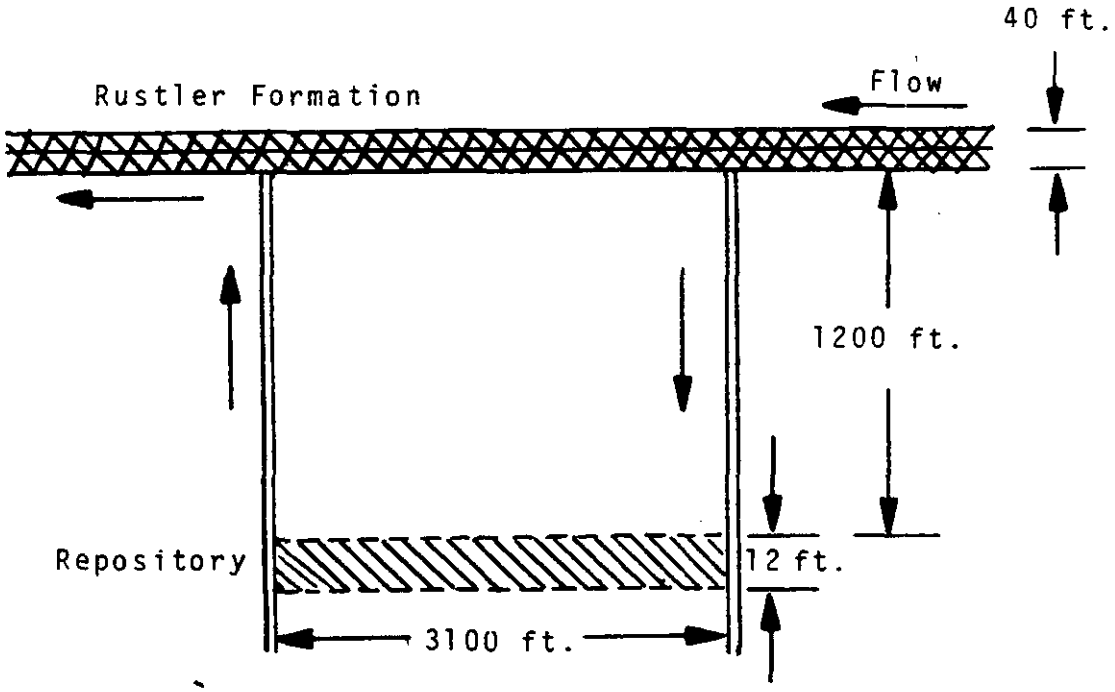

Figure 2. Schematic Diagram of Communication Event 2
Modified From WIPP FEIS Figure 9-11 (Ref. 2)

2) Dilution factor due to movement between repository and well, D_2:

Because of the adsorption and desorption of nuclides as they pass through the rock, the movement of nuclides in the aquifer is slower than the velocity of water.

The nuclide velocity is given by the water velocity divided by the retardation factor B

$$V_n = V_w/B \qquad (4)$$

$$B = 1 + \frac{\rho}{\theta} K_d \qquad (5)$$

where:

V_n = nuclide velocity
V_w = water velocity, 15 ft/yr.
θ = formation porosity = 0.1
ρ = formation density = 2 gm/cc
K_d = distribution coefficient = 1 mℓ/gm for all uranium isotopes and 2.4E+03 mℓ/gm for all plutonium isotopes (Reference 2, Table 2.5-12)

The values of the above parameters are from references 1 and 2. The time of travel between the repository breach and the well is then calculated from

$$T = \frac{dB}{V_w} \qquad (6)$$

where

d = distance between repository breach and well = 3 miles or 15840 ft.

If a repository breach occurs one thousand years after waste emplacement, all uranium isotopes and all plutonium isotopes will reach the well in about twenty thousand and fifty million years respectively (There are other radionuclides in the waste but their radiological impact is not significant compared to the plutonium and uranium isotopes).

Because of radioactive decay, the activity decreases as the nuclides travel in the direction of the well. The decrease in activity is given by the following dilution factor

$$D_2 = \exp(-\lambda T) \qquad (7)$$

where

λ = decay constant of isotope, $yrs.^{-1}$

T = time of travel between breach and well, yrs.

For Pu, the retardation factor is so large that all the isotopes decay before reaching the well. The dilution factor D_2 is zero. However, there is evidence that the transport model and the distribution coefficients do not account fully for certain observed phenomena. Thus, Seitz et al (Reference 4) observed in their studies of radionuclide migration in geologic media that 2.6% of the plutonium traveled at a relative migration rate (Vn/Vw) greater than 0.001. Dosch and Lynch (Reference 5) also observed that the K_d values for rare earth radionuclides decreased when plywood extract was added to the brine. This was attributed to the formation of more soluble complexes between radionuclides and organic molecules.

In this report, it will be assumed that 1% of the Pu-239 and Pu-240 in CH-TRU waste is in a chemical form which allows it to move with a Rustler water velocity of 15 ft/yr (K_d = 0). On the bases of the Seitz studies, this is highly conservative. Since the distance between the breach and the well is 3 miles, the travel time is thus 1,000 years. The dilution factors D_2 (including the assumption that 1% of Pu moves with water velocity of 15 ft/yr) for Pu-239 and Pu-240 are therefore 9.7E-03 and 8.9E-03 respectively.

The dominant uranium isotopes in CH-TRU waste after 21,000 years time of breach plus time of travel to the well for

uranium nuclides are U-233 (from the initial inventory) U-234 (derived mainly from Pu-238) and U-235 (derived from Pu-239), and U-236 (derived from Pu-240).

Because of the long half-lives of U-233, U-234, U-235, and U-236, the dilution factors D_2 are 0.91, 0.94, 1.0 and 1.0 respectively.

3) Dilution factor to make brine potable, D_3.

The brine coming out of the repository and entering the Rustler aquifer is so saline that it cannot be used for irrigation or for drinking. It is assumed that the brine will be diluted in the aquifer as it travels toward the well. Several dilution mechanisms can be postulated but they will not be discussed in detail in this report.

Regional data on the quality of Rustler well water are sparse. However, a Rustler well at James Ranch, about three miles southwest of the center of the WIPP site is reported to have a TDS content of 3240 mg/ℓ (Ref. 1). In this report it will be assumed that saturated brine is diluted with water having a TDS content of 3000 mg/ℓ to form water with a TDS of 5000 mg/ℓ at the well.

Let w denote the number of units of water with a TDS content of 3000 mg/ℓ which must be added to one unit of saturated brine (at 410,000 mg/ℓ) to yield water with a TDS content of 5000 mg/ℓ. w is then found by solving the equation

$$\frac{(1 \times 410{,}000) + (w \times 3000)}{1 + w} = 5000 \text{ mg/ℓ}$$

Rounded to two significant figures. w = 200 units. The dilution factor to make brine potable, D_3, is then 5E-03.

4) Treated water used for drinking, D_4.

Because of the relatively high salt content, it is assumed that water is treated before being used as drinking water for people. Such a treatment system could be reverse osmosis. In addition to the halite, treatment is assumed to remove 90% of any radium, thorium, uranium and plutonium in the water. The dilution factor for treatment of water, D_4, is thus 1.0E-01. The sludge resulting from reverse osmosis treatment will have a higher radioactive concentration than the aquifer water. The path of the sludge in the biosphere will not be studied in this report.

5) Dilution factor for water-cow-milk pathway, D_5.

In this case, it is assumed that the untreated well water is used as drinking water for a cow. The members of the farm family who own the cow drink the cow's milk.

It is assumed that the cow drinks 60 liters of water per day (Ref. 6, Table E-3) and the transfer coefficient used is 5E-04 and 1.5E-06 Ci/ℓ milk per Ci/day ingested for U and Pu respectively (Ref. 7, Table 3). The dilution factors for the water-cow-milk pathway, D_5, are thus 3.0E-02 and 9.0E-05 for uranium and plutonium respectively.

V. Isotope Inventory

The values for the activity concentrations in the repository at the time of the breach and the half-life of the nuclides are presented in Table I.

Table I

Radionuclide Concentrations at Time of Breach

Radionuclide	Half-life	Activity in Waste
	yrs	Ci/ℓ
U-233	1.6E+05	8.4E-06
U-234	2.4E+05	7.2E-08
U-235	7.0E+08	3.8E-08
U-236	2.3E+07	1.5E-07
Pu-239	2.4E+04	2.3E-03
Pu-240	6.5E+03	5.3E-04

The U-233 activity is based on 1500 Ci that originated from the light water breeder reactor core program. It is assumed that this activity is uniformly distributed in the repository. The U-234 activity is obtained by complete conversion of all the originally emplaced Pu-238 (concentration is 2.0E-04 Ci/ℓ at time of emplacement). The U-235 activity is based on the assumption that 45 per cent of the initially emplaced Pu-239 has been converted to U-235 (amount of Pu-239 converted in 21,000 years) and that this activity is available for travel to the well following the breach. This simplified source term is conservative and yields higher concentration at the well than the more rigorous source term resulting from the transport model of Lester et al (Reference 8). Similarly, the U-236 activity is based on the assumption that 89 per cent of the initially emplaced Pu-240 has been converted to U-236. The Pu-239 and Pu-240 activities are the concentrations in the repository 1,000 years after closure of the repository. As discussed on Page 8, it is assumed that 1% of this concentration moves with the speed of the Rustler.

VI. Summary of Dilution Mechanisms for Different Pathways

The dilution factors for the pathway of interest and the activity concentrations of water and milk prior to consumption are presented in Table II.

Table II

Summary of Dilution Factor Calculations

Path	Dilution Factor Formula	Dilution Factor	Activity Concentration in water or Milk pCi/ℓ	NRC limits * pCi/ℓ
Treated water used for drinking	D_1 D_2 D_3 D_4			
U-233		5.9E-06	5.0E+01	3E+04
U-234		6.1E-06	4.4E-01	3E+04
U-235		6.5E-06	2.5E-01	3E+04
U-236		6.5E-06	9.8E-01	3E+04
Pu-239		6.3E-08	1.4E+02	5E+03
Pu-240		5.8E-08	3.1E+01	5E+03
Water-cow-milk	D_1 D_2 D_3 D_5			
U-233		1.8E-06	1.5E+01	see above
U-234		1.8E-06	1.3E-01	
U-235		2.0E-06	7.6E-02	
U-236		2.0E-06	3.0E-01	
Pu-239		5.7E-11	1.3E-01	
Pu-240		5.2E-11	2.8E-02	

In studying Table II, it should be remembered that the concentrations for the Pu-nuclides appear 1,000 year after the breach while the concentrations for the U-nuclides appear 20,000 years after the breach.

*Reference 9

The EPA national interim primary drinking water regulations limit the gross alpha particle activity (including radium-226 but excluding radon and uranium) to 15 pCi/ℓ (Ref. 10). The EPA environmental protection standards for disposal of residual radioactive material from inactive uranium processing site limit the concentration in water of all uranium radionuclides to 10 pCi/ℓ. The water concentrations of U-233 exceed the limits of Ref. 11 while the water concentration of Pu-239 and Pu-240 exceed the limits of Ref. 10.

VII. 50-year Dose Commitments

The water and milk consumption values, and the dose commitment factors used in the calculations are presented in Tables III, IV and V.

Table III

Water and Milk Consumptions Values (6)

Exposed Individual	Annual Water Consumption ℓ/yr	Annual Milk Consumption ℓ/yr
Infant	330	330
Child	510	330
Teenager	510	400
Adult	730	310

Table IV

50-Year Ingestion Dose Commitment Factors for Bone from a one year intake (3), mrem/pCi

Exposed Individual	U-233 and U-234	U-235 and U-236	Pu-239 and Pu-240
Infant	5.1E-03	4.7E-03	1.5E-03
Child	3.7E-03	3.4E-03	1.4E-03
Teenager	1.2E-03	1.1E-03	8.3E-04
Adult	8.7E-04	8.0E-04	7.9E-04

Table V

50-Year Ingestion Dose Commitment Factors
for Total Body from a one year intake (Ref. 3), mrem/pCi

Exposed Individual	U-233 and U-234	U-235 and U-236	Pu-239 and Pu-240
Infant	3.9E-04	3.6E-04	3.5E-05
Child	2.3E-04	2.1E-04	3.3E-05
Teenager	7.5E-05	7.1E-05	2.0E-05
Adult	5.3E-05	5.0E-05	1.9E-05

The 50-year dose commitments were calculated using equation (2) and are presented in Tables VI, VII, and VIII.

Table VI

50-Year Dose Commitments Due to U-233
from Drinking Treated Water or Milk for one year (mrem)

Exposed Individual	Drinking of Treated Water		Drinking of Milk	
	Bone	Total Body	Bone	Total Body
Infant	8.4E+01	6.4	2.5E+01	1.9
Child	9.4E+01	5.9	1.8E+01	1.1
Teenager	3.1E+01	1.9	7.2	4.5E-01
Adult	3.2E+01	1.9	4.0	2.5E-01

Table VII

50-Year Dose Commitments Due to U-234, U-235, and U-236
from Drinking Treated Water on Milk for one year (mrem)

Exposed Individual	Drinking of Treated Water		Drinking of Milk	
	Bone	Total Body	Bone	Total Body
Infant	2.6	2.0E-01	8.0E-01	6.1E-02
Child	3.0	1.8E-01	5.8E-01	3.6E-02
Teenager	9.6E-01	6.1E-02	2.3E-01	1.5E-02
Adult	1.0	6.2E-02	1.3E-01	8.0E-03

Table VIII

50-Year Dose Commitments Due to Pu-239 and Pu-240
from Drinking Treated Water or Milk for one year (mrem)

Exposed Individual	Drinking of Treated Water		Drinking of Milk	
	Bone	Total Body	Bone	Total Body
Infant	8.5E+01	2.0	7.8E-02	1.8E-03
Child	1.2E+02	2.9	7.3E-02	1.7E-03
Teenager	7.2E+01	1.7	5.2E-02	1.3E-03
Adult	9.9E+01	2.4	3.9E-02	9.3E-04

VIII. Discussion

A simple model is used to calculate the dose commitments to individuals resulting from the use of well water contaminated by a breach of the WIPP repository. The safety factors of the barriers are quantified in terms of dilution factors. The calculations are kept simple but conservative. For example, it is assumed that a U-shaped connection can occur between the Rustler aquifer and the repository even though a recent hydrological study found this connection as unrealistic when the density of the brine is taken into account (Ref. 12). Also, it is assumed that the leach rate of waste is equal to the leach rate of salt, and that 1% of the Plutonium moves with the speed of the water. For plutonium these ultra-conservative assumptions may be partialy offset by the use of the EPA dose conversion factors for transuranic elements (Table A 3-5, Reference 13). These EPA factors for the mobile fraction of plutonium would result in doses 33 to 165 times higher than those based on NUREG-0172.

The concentrations of all radionuclides at the well are less than the NRC release limits to the uncontrolled environment (9). The concentrations in the treated well water of U-233, Pu-239, and Pu-240,

all radionuclides originally emplaced with the wastes, exceed the EPA drinking water limits. The concentration of U-233 in treated water exceeds the EPA limits by a factor of 3 while the combined concentration of Pu-239 and Pu-240 in treated well water exceeds the EPA limit by a factor of 11. The Pu concentration exceeds the EPA limit because it has been assumed that 1 percent of the plutonium inventory moves with the speed of groundwater. The combined concentration of U-234, U-235, and U-236 in treated well water, all decay products of Pu isotopes, is a factor of nine less than the EPA limit.

Other barriers, that could lower the release of radionuclides, can be imagined in addition to the ones discussed. For example, the salt surrounding the WIPP repository contains significant amounts of clay which is known to selectively bind uranium and plutonium (Ref. 14). Two clay seams are reported at a depth of 2124 to 2134 feet which is 20 to 30 feet above the floor of the repository. The clay could thus act as a barrier with a significant dilution factor. Data from the planned WIPP experiment may help quantify this dilution factor.

Based on the conservative assumptions used, the planned inventory of radionuclides in the waste would not present a significant risk to health from a well three miles from the site, even if a breach and transport of the waste to the well is assumed. For this to be true, however, it is particulary important that the major fraction of the plutonium be retarded by adsorption on the rock during its passage from the repository to the well.

REFERENCES

1. U.S. Department of Energy, Final Environmental Impact Statement, Waste Isolation Pilot Plant, (DOE/EIS-0026-D), October 1980, 2 volumes.

2. U.S. Department of Energy, Waste Isolation Pilot Plant, Safety Analysis Report, 1980, 5 volumes.

3. Homes, G.R., and Soldat, J.K., Age Specific Radiation Dose Commitment Factors for a One-Year Chronic Intake, (NUREG 0172), November 1977.

4. Seitz, M.G., et al, Studies of Nuclear Waste Migration in Geologic Media, Annual Report, November 1976-October 1977, (ANL 78-8), March 1978.

5. Dosch, R.G., and A.W. Lynch, Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant (WIPP) Site in New Mexico, (SAND-78-0297), June 1978.

6. 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, (Regulatory Guide 1.109), October 1977.

7. Ng, Y.C. et al., Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices. Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere, (USAEC Report UCRL-50163), Part IV, 1968.

8. Lester, D.H., Jansen, G., and Burkholder, H.C., Migration of Radionuclide Chains through an Adsorbing Medium, A.I.Ch.E. Symposium Series, v. 71, 1975.

9. Code of Federal Regulations Title 10 part 20, Appendix A, Table II, Concentration in air and water above Natural Background.

10. Code of Federal Regulations Title 40, part 141.15, Maximum contaminant level for radium-226, radium-228, and gross alpha particle radioactivity in community water systems.

11. Code of Federal Regulations Title 40 part 192. Environmental Protection Standards for Uranium Mill Tailings. Section 03 Standards.

12. D'Appolonia, Modeling Verification Studies Long Term Waste Isolation Assessment. Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico, (Project No. NM78-648-701), January 1981.

13. U.S. Environmental Protection Agency, Proposed Guidance on Transuranic Elements (EPA 520/4-77-016), 1977.

14. U.S. Environmental Protection Agency, Technical Support of Standards for High-Level Radioactive Waste Management. Task C Report. Assessment of Migration Pathways, (EPA 520/4-79-007C), 1979.