EEG-66

INDIVIDUAL RADIATION DOSES FROM TRANSURANIC WASTE BROUGHT TO THE SURFACE BY HUMAN INTRUSION AT THE WIPP

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Environmental Evaluation Group
New Mexico

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FOREWORD

The purpose of the New Mexico Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health and safety and the environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository for the disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Public law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the original contract DE-AC04-79AL10752 through DOE contract DE-AC04-89AL58309. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, continues the authorization.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. Another important function of EEG is the independent environmental monitoring of background radioactivity in air, water, and soil, both on-site and off-site.

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TABLE OF CONTENTS

1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) standards that are applicable for long-term disposal of radioactive transuranic wastes at the Waste Isolation Pilot Plant (WIPP) facility are codified in 40 CFR Part 191. These standards require the U.S. Department of Energy (DOE) to evaluate the effects of releases from the repository for both undisturbed and disturbed conditions. Undisturbed conditions are those that could occur from natural causes without any human actions. Disturbed conditions are those caused by inadvertent human actions such as drilling through the repository during oil and gas exploration. Deliberate intrusion into the repository does not have to be considered.

Releases from undisturbed events must be evaluated for the radiation dose* to individuals (§191.15) and the effect on groundwater quality (§191.24) as well as for the cumulative release of transuranics to the accessible environment (the Containment Requirement, §191.13). Releases from disturbed events are required to be evaluated only for the Containment Requirements. The Compliance Certification Application (CCA) that DOE submitted to EPA in October 1996 did not evaluate individual doses from disturbed events (U.S. DOE 1996c).

Most other countries with nuclear waste require that radiological risk to an individual (individual radiation doses) be assessed for both undisturbed and disturbed scenarios. An OECD/IAEA International Review Group that evaluated the WIPP Project was concerned that individual doses had not been calculated and Sandia National Laboratories (SNL) provided estimates during the Group's January 1997 Carlsbad meeting (OECD/IAEA 1997).

The National Academy of Science (NAS) WIPP Committee in their review of SNL's 1992 Performance Assessment (PA) also concluded that the scope of the PA effort "must include performance measures that go beyond radionuclide release rates to the accessible environment" (NAS 1996).

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* Radiation doses in 40 CFR 191 and this report are the annual committed effective dose, which EPA defines as the committed effective dose resulting from a one-year intake of radionuclides released plus the annual effective dose caused by direct radiation.

Section 801 of the Energy Policy Act of 1992 (Public Law 102-486) required EPA to set standards to ensure protection of the health of individual members of the public from the proposed Yucca Mountain Project site for high-level radioactive waste. Section 801 also required the NAS to conduct a study providing guidance to EPA. One of the three questions the NAS was charged with addressing was "whether a health-based standard based upon doses to individual members of the public from releases to the accessible environment will provide a reasonable standard for protection of the health and safety of the general public". The NAS Committee on Technical Basis for Yucca Mountain Standards concluded that an individual dose standard was appropriate (NAS 1995). However the Committee did not agree on how the location and lifestyle of this individual should be defined.

Prior to the 1985 promulgation of 40 CFR 191 (which requires probabilistic analyses) WIPP human intrusion scenario calculations by EEG and DOE evaluated the individual dose with deterministic calculations. Several relevant reports were U.S. DOE 1980, Channell 1982, Woolfolk 1982, and Bard 1982. The latter three reports evaluated the effects of contaminated Castile brine releases to the surface while U.S. DOE 1980 considered only material brought to the surface in cuttings from a drillbit.

The Environmental Evaluation Group (EEG) concluded that it is appropriate to revisit the issue of individual doses from inadvertent human intrusion. The specific purpose of this report is to:

(1) calculate likely individual doses that would result from the same releases predicted by the CCA;
(2) determine whether these calculated doses exceed limits for radiation exposure from other activities;
(3) compare the stringency of an individual dose standard at WIPP with the release limits in 40 CFR Part 191;
(4) discuss the appropriateness and feasibility of reducing potential doses to an individual from human intrusion at WIPP.

Because of the above concerns the deterministic calculations in this report rely primarily on drilling related analyses in the CCA for the determination of source term.** Details of the scenarios for workers, individual members of the public and the population within 80 kilometers (50 miles) of the site are adapted from scenarios used in prior WIPP reports. Pathway analyses and dose conversion factors primarily use current methodology from EPA and U.S. Nuclear Regulatory Commission (NRC) reports.

**The CCA results were used because one purpose of the individual dose calculation is to compare results with probabilistic cumulative releases and it does not imply that EEG is in complete agreement with the assumptions and methodology used in the CCA. Also, during the summer of 1997 the EPA required DOE to recalculate releases using some different parameter values. The Performance Assessment Validation Tests (PAVT) resulted in calculated waste volume and radioactivity releases that were about twice those in the CCA. These higher values have been used in this report only to determine the magnitude of the 95% upper confidence level release.

2. SCENARIO DESCRIPTION

This section provides an overall description of the drilling scenario, exposed persons, and intrusion times. Some of the major assumptions are also presented. Other assumptions are included in the appendices with the calculation methodology.

2.1 Radionuclide Releases to Surface

Radioactive material will be brought to the surface from all boreholes that penetrate a waste room due to cuttings and cavings. Radioactive material may also be brought to the surface from spallation and/or direct brine release if these processes occur.

Cuttings. Cuttings is the repository material directly intercepted and ground up by the drill bit. This material is brought to the surface in the drilling fluid and settles out in the mud pit before the fluid is recirculated into the borehole. The volume of waste material included in cuttings is equal to the cross sectional area of the drill bit times the initial height of the waste storage room times the fraction of the room contents that is waste.

Cavings. Cavings is the material that is eroded from the borehole wall by the action of the flowing drilling fluid. This eroded material is brought to the surface in the drilling fluid. The amount of cavings depends on the erosion shear resistance of the waste at the time of drilling. The erosion shear resistance parameter is uncertain and is variable. This was a sampled parameter in the CCA and thus the volume of cavings was a variable. The median, mean, and maximum cavings volumes in the CCA were 0.68, 1.0, and 8.7 times the cuttings volume (Helton 1996).

Spallings. Spallings is contaminated material that will be carried to the surface if drilling fluid is expelled from the borehole by high pressure gas flowing into the borehole from the penetrated waste storage room. The gas pressure in the waste room must be greater than the hydrostatic pressure of the drilling fluid in order for spallings to occur. Hydrostatic pressure is about 8 megapascals (MPa) at the repository horizon. DOE sensitivity analysis of the CCA calculations indicated that spallings releases from first intrusions occur less than one-half the time prior to 3,000 years. The frequency and volumes of spallings release from second intrusions into a waste panel are less than for first intrusions.

Direct Brine Release. Direct release of brine containing dissolved radionuclides can occur from a waste room into a borehole if mobile brine (a quantity of brine greater than the residual brine saturation) is present in the waste room and the brine pressure is >8 MPa. In the CCA calculations direct brine releases occur less than 25% of the time for intrusions prior to 10,000 years. The frequency and volume of flows are greater for the E1E2 scenario than for the E1 or E2 scenario.

2.2 Borehole Drilling

The human intrusion scenario is assumed to be the E2 scenario used in the CCA. An exploratory oil or gas drill bit penetrates a repository waste storage room in the Salado formation at a depth of 655 m (2150 feet). Drilling fluid (drilling mud) is continuously circulated during drilling and is the mechanism for transporting cuttings and cavings from the waste room to the surface. This material settles out of the drilling fluid in the mud pit before the drilling fluid is recirculated into the borehole. Contaminated material in the mud pit is the source of radiation doses to drilling crew workers and to the public.

The E1E2 scenario is not explicitly modeled in this report but it is considered by Channell 1982 and the CCA. This scenario involves a first penetration (E1) into a pressurized brine reservoir in the underlying Castile Formation. An E2 borehole penetrates the repository at a later time. This scenario has the potential to result in somewhat greater contaminated brine releases to the surface than from an E2 scenario alone. Also, the E1E2 scenario includes cuttings and cavings releases from two boreholes rather than one.

2.3 Exposure of Drilling Crew Members

Members of the drilling crew are subjected to external exposure as the contaminated drilling fluid flows through the shale shaker to the mud pit. Figure 2-1 shows a diagram of a typical drilling rig site layout. The contaminated material in the mud pit is assumed to be evenly mixed (horizontally and vertically) with all the cuttings produced in drilling to a depth of 2100 m (the approximate depth of much of the current oil production around the WIPP site). This contaminated material is assumed to deliver an external dose to a worker standing at the edge of the mud pit for a total of 12 hours in the approximate 60-day period needed to complete the well.

The mud pit is assumed to be too moist for resuspension during drilling. However after drilling ceases (about 45 days before well completion) the mud pit will dry out and resuspension will occur. It is assumed that workers will be located at the drilling rig (100 meters from the center of the mud pit) for 80-hours and will inhale resuspended radionuclides during the 37% of the time they are down wind from the dried mud pit. The rational for not assuming that the mud pit would be filled (reclaimed) is discussed in Appendix A.

2.4 Annual Exposure to a Nearby Resident

In Case I the resident farmer is assumed to be living in a ranch house 800 meters from the mud pit in the prevailing downwind direction. This person is present at his residence for 350 days a year and spends 73% of the time indoors. He is exposed to resuspended material from the mud pit and receives a radiation dose from: (1) inhalation; (2) direct radiation from deposited material; (3) ingestion of dirt; and (4) ingestion of beef.

Case II (the resident non-farmer case) is a bounding case. The resident non-farmer is assumed to live at the edge of the mud pit and be in his home 73% of the hours in a year. Radiation dose is received from inhalation, direct radiation, and ingestion of dirt.

Case III (the non-resident farmer case) is another bounding case. The non-resident farmer grows vegetables in the mud pit which has been made fertile with imported top soil. Non-contaminated water from the Dewey Lake formation is assumed to be available for irrigation. This person is assumed to receive a radiation dose only from contaminated vegetables via the soil-to-crop pathway.

2.5 Exposure of Population

The annual population dose to the resident population within 80 kilometers (50 miles) of the WIPP site is estimated. This dose is from inhalation of material resuspended from the mud pit. Average annual atmospheric dispersion values are used.

2.6 Times of Intrusion

For contact-handled transuranic (CH-TRU) waste the intrusion times evaluated were 100, 350, 700, 1000, 5,000 and 10,000 years after repository closure for the E2 scenario.

Intrusions into a remote-handled transuranic waste (RH-TRU) canister were evaluated at 100 and 350 years after repository closure for direct radiation. Inhalation doses were evaluated for the 10,000 year period.

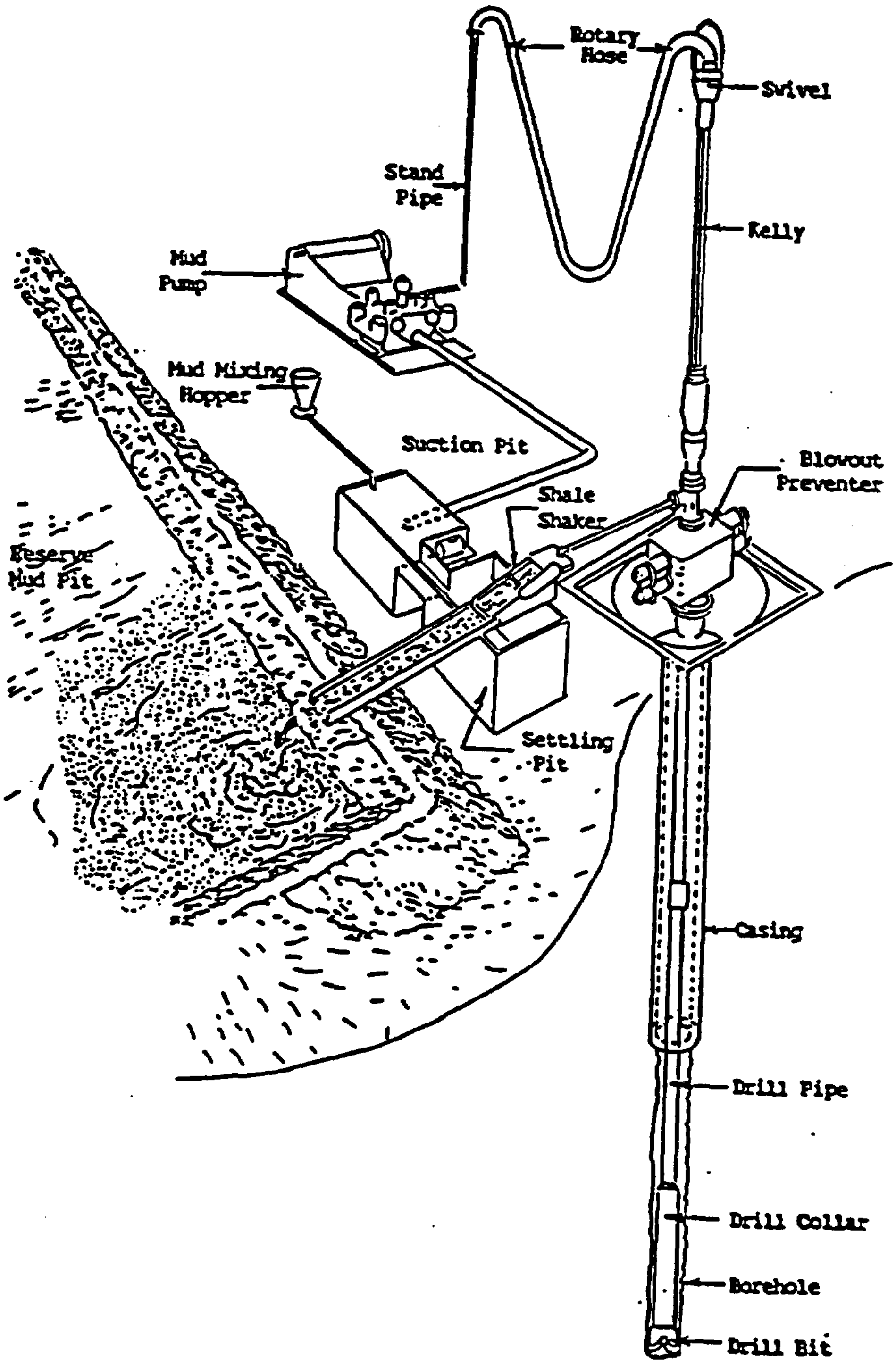

Figure 2-1. Drilling Fluid Circulation Diagram

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3. SOURCE TERM

The source term is defined as the quantity of radionuclides brought to the surface as a result of a drilling event. Contact-Handled Transuranic Waste (CH-TRU) comprises about 96% of the volume of waste expected to be brought to WIPP. The remainder of the waste will be Remote-Handled TRU (RH-TRU) which contains about 10% of the radioactivity at time of closure. This source term will be developed separately for CH-TRU and RH-TRU since they are not placed together in the repository and both would not be expected to be impacted by the same intrusion.

3.1 CH-TRU Waste

3.1.1 Emplacement and Volumes of Waste

The WIPP repository is limited by federal statue to a capacity of 175,600 m^3 of waste. The volume of CH-TRU is expected to be 168,500 m^3. This waste is contained in either 0.208 m^3 (55-gallon) drums or in 1.7 m^3 Standard Waste Boxes. The containers will be stacked 3 high in waste storage rooms that are 90 m long, 10 m wide, and 3.96 m high. Waste containers will also be emplaced in panel drifts and access drifts.

The waste form is not homogeneous but is highly variable, including debris, sludges, metals, and glasses. The radionuclide concentration also varies over several orders of magnitude and there is considerable variation in radionuclide composition. The CCA documents DOE's sampling of 569 waste streams in order to capture the variability in radionuclide concentration and composition.

The amount of cuttings waste intercepted by the drilling bit is 0.301 m^3. This volume is the product of the area of the 0.311 m (12.25 inch) diameter drill bit and the height of the room (3.96 m). The amount of cavings is variable and this leads to a distribution of cuttings plus cavings volumes. In the CCA, the median, mean, and maximum volumes of cuttings plus cavings were 0.51 m^3, 0.60 m^3, and 3 m^3. These volumes need to be multiplied by the fraction of a room volume that contains waste (0.384) to get the volumes of waste brought to the surface. The source term in this report uses the mean and maximum volumes of waste (0.230 m^3 and 1.15 m^3).

Releases from spallings and direct brine release are complex and are related to the amount of pressure and brine in waste rooms at the time of intrusion rather than to the cuttings plus cavings volume. However, for modeling simplicity, the waste volumes brought to the surface by spallings and direct brine release are assumed to be 50% of the value of cuttings and cavings for all intrusion times except at 100 years (because modeling shows that pressures are minimal in the first few hundred years). This additional volume is assumed to have the same radionuclide concentration as the cuttings and cavings. The 50% value is similar to the typical effect on the complementary cumulative distribution function (CCDF) in the CCA from spallings plus direct brine release.

3.1.2 CH-TRU Radionuclide Inventory

The average CH-TRU radionuclide concentrations were obtained from Table 3-1 of U.S. DOE 1996a. The maximum waste stream, taken from Table 1 in Appendix B-2, was the 2800 m^3 of residue wastes at the Rocky Flats Environmental Technology Site (RFETS) and contains high concentrations of ^{239}Pu, ^{240}Pu, and ^{241}Am. The heat source waste from the Savannah River Site (1480 m^3) which contains high ^{238}Pu concentrations was used as the maximum source at 100 years after repository closure.

The curies of the key radionuclides brought to the surface in the mean (0.23 m^3) and in the maximum volumes of cuttings plus cavings (1.15 m^3) for typical 55-gallon drums are shown in Table 3-1. The residue waste is to be packaged in pipe containers positioned within 55-gallon drums. The maximum volume of waste in a pipe container is about 0.0445 m^3 and so the waste volumes brought to the surface are only 0.214 of those from typical drums.

Table 3-1. Calculated Curies of CH-TRU Waste Brought to Surface[1]

	Nuclide				
Intrusion Time, Years	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Am	Total
Mean Concentration, Mean Volume					
100	1.20	1.07	0.283	0.552	3.11
350	0.249	1.59	0.414	0.555	2.81
700	—	1.58	0.401	0.318	2.30
1,000	—	1.56	0.387	0.197	2.14
5,000	—	1.39	0.253	—	1.64
10,000	—	1.20	0.149	—	1.35
Mean Concentration, Maximum Volume					
100	5.99	5.36	1.41	2.76	15.5
350	1.25	7.95	2.07	2.78	14.1
700	—	7.86	2.00	1.59	11.5
1,000	—	7.80	1.94	0.984	10.7
5,000	—	6.95	1.26	—	8.21
10,000	—	6.02	0.744	—	6.76
Maximum Concentration, Mean Volume					
100	18.5	1.42	0.180	0.297	20.4
350	0.0101	4.82	1.07	1.97	7.87
700	—	4.75	1.03	1.12	6.90
1,000	—	4.73	0.999	0.693	6.42
5,000	—	4.22	0.655	—	4.88
10,000	—	3.64	0.385	—	4.03
Maximum Concentration, Maximum Volume					
100	92.3	7.10	0.909	1.48	102.
350	0.0499	24.0	5.37	9.87	39.3
700	—	23.8	5.18	5.63	34.6
1,000	—	23.5	4.99	3.47	32.0
5,000	—	21.0	3.27	—	24.3
10,000	—	18.2	1.92	—	20.1

[1] The waste volumes brought to the surface in cuttings and cavings are 0.23m^3 and 1.15 m^3 for mean concentration wastes and for maximum concentration wastes at 100 years. Maximum concentration wastes at later times have volumes of 0.0492 m^3 and 0.246 m^3. Volumes from intrusion at 350 years and later are increased by 50% to approximate typical spallings and direct brine releases.

3.2 RH-TRU Wastes

3.2.1 Volumes of RH-TRU Waste

RH-TRU canisters are to be inserted horizontally into the walls of WIPP waste storage rooms. The cylindrical canisters are about 3.05 m (10 feet) long and have an internal diameter of 0.572 m (1.88 feet). A 0.311 m (12.25 inch) diameter drill bit that encountered the horizontal canister would drill through a maximum effective depth of about 0.542 m. Thus the volume of RH-TRU waste brought up by cuttings alone would be 0.0413 m^3.

Cavings to cuttings volume ratios are assumed to be the same as for CH-TRU waste. Therefore the mean and maximum cavings volumes would be 1.0 and 8.7 times the cuttings volume. The effective depth of waste for cavings is less than for cuttings since the cavings mechanism will not begin until the entire diameter of the drill bit has penetrated the cylindrical canister. This depth is about 0.479 m.

These assumptions lead to a mean cuttings plus cavings volume for RH-TRU of 0.0778 m^3. The maximum volume of waste would be 0.359 m^3, which is about 40% of the contents of a canister.

Releases from spallings and direct brine release are assumed to be zero for RH-TRU canisters. The canisters are isolated from the waste storage rooms and the marker beds so there appears to be little chance of having mobile brine present about and within the canister. Gas generation and some pressurization could occur within an RH-TRU canister but volumes are so limited if the canister maintains its integrity that any spallings effect should be minimal.

3.3.2 RH-TRU Radionuclide Inventories

The RH-TRU radionuclide inventories used in the CCA are derived from Appendix C of the Baseline Inventory Report (BIR) Revision 3 (U.S. DOE 1996a). The Revision 3 inventory, decayed to 1995, is further decayed to the year 2033 for use in the CCA.

The average radionuclide concentration of the Hanford RH-TRU was chosen as the mean concentration. The Hanford RH-TRU has the highest average radioactivity concentrations for most radionuclides and also contains 81% of the volume of all RH-TRU expected to be generated.

The maximum RH-TRU radionuclide concentration was taken from Hanford waste stream RL-W272. Data on this waste stream is presented in Appendix P of U.S. DOE 1996a. This 24 m^3 waste stream had the highest concentrations noted for RH-TRU in Appendix P. However, a number of RH-TRU waste streams did not have any radionuclide information. This waste stream's total radioactivity concentration (7.8 Ci ℓ^{-1}) is 34% of the maximum concentration allowed for an RH-TRU canister (23 Ci ℓ^{-1}) by agreement with the State of New Mexico. The calculated curies of RH-TRU waste brought to the surface are shown in Table 3-2.

Table 3-2. Calculated Curies of RH-TRU Waste Brought to Surface

Nuclide	Hanford Average Concentration				Hanford Max Concern Maximum Volume	
	Mean Volume		Max Volume			
	+100y	+350y.	+100y.	+350y.	+100y.	+350y
^{90}Sr	9.40×10^{-2}	2.40×10^{-4}	4.34×10^{-1}	1.12×10^{-3}	$2.39 \times 10^{+1}$	6.10×10^{-2}
^{90}Y	9.40×10^{-2}	2.40×10^{-4}	4.34×10^{-1}	1.12×10^{-3}	$2.39 \times 10^{+1}$	6.10×10^{-2}
^{137}Cs	1.12×10^{-1}	3.40×10^{-4}	5.17×10^{-1}	1.61×10^{-3}	$2.82 \times 10^{+1}$	8.61×10^{-2}
^{137}Ba	1.06×10^{-1}	3.20×10^{-4}	4.89×10^{-1}	1.52×10^{-3}	$2.67 \times 10^{+1}$	8.15×10^{-2}
^{238}Pu	6.10×10^{-3}	8.60×10^{-4}	2.81×10^{-2}	3.95×10^{-3}	3.00×10^{-1}	4.29×10^{-2}
^{239}Pu	1.29×10^{-1}	1.29×10^{-1}	5.95×10^{-1}	5.92×10^{-1}	5.59×10^{0}	5.51×10^{0}
^{240}Pu	6.47×10^{-2}	6.32×10^{-2}	2.99×10^{-1}	2.91×10^{-1}	2.76×10^{0}	2.68×10^{0}
^{241}Am	1.11×10^{-1}	7.40×10^{-2}	5.10×10^{-1}	3.41×10^{-1}	----	----

4. CALCULATED DOSES TO WORKERS

4.1 Doses from CH-TRU

4.1.1 External Radiation Dose at Shale Shaker

The calculated external radiation dose to a worker at the shale shaker from CH-TRU waste brought to the surface is shown in Table 4-1. Details of the assumptions and methodology used in calculating these doses is in Appendix A.1 and A.2.

Calculated doses are very small because CH-TRU wastes contain very small amounts of non-TRU radionuclides and the TRU radionuclides produce only weak and infrequent gamma radiations. The doses never exceed 0.3 mrem, even for the maximum concentrations and volumes at 100 years. Over 95% of the dose up to 1000 years is due to ^{241}Am, which decays with a 432 year half-life and is not a factor at later times. Doses from the plutonium radioisotopes never contribute as much as 0.1 mrem to the dose.

Table 4-1. External Radiation Dose to Worker at Shale Shaker from CH-TRU Waste (Millirem - Committed Effective Dose)

Year	Mean Concentration			Maximum Concentration		
	Mean Vol	Max Vol	Comment	Mean Vol	Max Vol	Comment
100	1.3×10^{-2}	6.4×10^{-2}	98% ^{241}Am	8.4×10^{-3}	4.2×10^{-2}	80% ^{241}Am, 18% ^{238}Pu
350	1.3×10^{-2}	6.5×10^{-2}	98% ^{241}Am	4.6×10^{-2}	2.3×10^{-1}	98% ^{241}Am
700	7.5×10^{-3}	3.7×10^{-2}	97% ^{241}Am, 3% ^{239}Pu	2.6×10^{-2}	1.3×10^{-1}	98% ^{241}Am, 2% ^{239}Pu
1,000	4.7×10^{-3}	2.4×10^{-2}	95% ^{241}Am, 4% ^{239}Pu	1.6×10^{-2}	8.2×10^{-2}	96% ^{241}Am, 3% ^{239}Pu
5,000	1.9×10^{-4}	9.3×10^{-4}	89% ^{239}Pu, 11% ^{240}Pu	5.6×10^{-4}	2.8×10^{-3}	91% ^{239}Pu, 9% ^{240}Pu
10,000	1.6×10^{-4}	7.8×10^{-4}	92% ^{239}Pu, 8% ^{240}Pu	4.7×10^{-4}	2.3×10^{-3}	94% ^{239}Pu, 6% ^{240}Pu

4.1.2 External Radiation Dose at Mud Pit

The calculated external radiation dose to a worker standing at the edge of the mud pit is shown in Table 4-2. Details of the methodology are included in Appendices A.1 and A.3.

Calculated doses are small and over 95% are due to ^{241}Am from 100 to 1000 years. The maximum concentration - maximum volume dose is only 0.77 mrem at 350 years and this is a low probability event.

Table 4-2. External Radiation Dose to Worker at Mud Pit from CH-TRU Waste (Millirem - Committed Effective Dose)

Year	Mean Concentration			Maximum Concentration		
	Mean Vol	Max Vol	Comment	Mean Vol	Max Vol	Comment
100	4.4×10^{-2}	2.2×10^{-1}	98% ^{241}Am	2.8×10^{-2}	1.4×10^{-1}	80% ^{241}Am, 17% ^{238}Pu
350	4.4×10^{-2}	2.2×10^{-1}	98% ^{241}Am	1.5×10^{-1}	7.7×10^{-1}	99% ^{241}Am
700	2.6×10^{-2}	1.3×10^{-1}	97% ^{241}Am, 3% ^{239}Pu	8.9×10^{-2}	4.4×10^{-1}	98% ^{241}Am, 2% ^{239}Pu
1,000	1.6×10^{-2}	8.0×10^{-2}	95% ^{241}Am, 4% ^{239}Pu	5.6×10^{-2}	2.8×10^{-1}	96% ^{241}Am, 3% ^{239}Pu
5,000	6.3×10^{-4}	3.2×10^{-3}	90% ^{239}Pu, 10% ^{240}Pu	1.9×10^{-3}	9.4×10^{-3}	91% ^{239}Pu, 9% ^{240}Pu
10,000	5.3×10^{-4}	2.7×10^{-3}	93% ^{239}Pu, 7% ^{240}Pu	1.6×10^{-3}	7.9×10^{-3}	94% ^{239}Pu, 6% ^{240}Pu

4.1.3 Inhalation Dose at Drilling Rig

Calculated inhalation doses to a worker at the drilling rig from resuspension of CH-TRU wastes from the mud pit are shown in Table 4-3. The inhalation doses are significant compared to the external doses and since they are due to long-lived transuranic radionuclides they decrease slowly with time (the doses at 10,000 years are 21-30% of those at 100 years after closure).

The probability of intrusions into CH-TRU waste during the 10,000-year regulatory period is high with the drilling rates that DOE is required to use in the CCA (46.8 Boreholes km^{2} in 10,000 years). There is a >99% probability of at least one intrusion into CH-TRU waste and a >57% probability there will be more than 4 intrusions. Even for the RFETS residues (which would be about 7.2% of the drums in the repository) there is a 31% probability of at least one intrusion. Also, from the CCA, there is a 10% probability that the volume of cuttings plus cavings released would be ≥ 0.87 m^3.

Table 4-3. Inhalation Dose to Worker at Drilling Rig from CH-TRU Waste (Millirem - Committed Effective Dose)

Year	Mean Concentration			Maximum Concentration		
	Mean Vol	Max Vol	Comment	Mean Vol	Max Vol	Comment
100	38	190	36% ^{238}Pu, 35% ^{239}Pu	240	1200	90% ^{238}Pu, 8% ^{239}Pu
350	36	180	57% ^{239}Pu, 20% ^{241}Am	100	500	61% ^{239}Pu, 26% ^{241}Am
700	29	150	68% ^{239}Pu, 17% ^{240}Pu	88	440	68% ^{239}Pu, 17% ^{241}Am
1,000	27	140	73% ^{239}Pu, 18% ^{240}Pu	81	410	73% ^{239}Pu, 16% ^{240}Pu
5,000	21	100	85% ^{239}Pu	62	310	87% ^{239}Pu
10,000	17	86	89% ^{239}Pu	51	250	91% ^{239}Pu

4.2 Doses from RH-TRU

4.2.1 Dose at Shale Shaker

Details of the assumptions and methodology necessary to calculate doses to a worker at the shale shaker are in Appendix A.1 and A.2. The results are shown in Table 4-4. Over 99% of the dose at 100 years after closure was due to ^{137m}Ba. At 350 years ^{241}Am comprises 88% of the total dose for the average waste concentration. The maximum concentration waste (which does not contain ^{241}Am) at 350 years is 75% ^{137m}Ba and 19% ^{239}Pu.

These doses are minimal, even for the maximum concentration wastes at 100 years.

4.2.2 Dose at Mud Pit

Details of the calculation of doses to a worker at the edge of the mud pit are in Appendix A.3. The results are shown in Table 4-5. Over 97% of the dose at 100 years for the average concentration wastes was due to ^{137m}Ba. About 2.0% came from ^{241}Am and bremsstrahlung radiation from ^{90}Y contributed about 0.6%. Over 99% of the dose from the maximum concentration waste (which doesn't contain ^{241}Am) was due to ^{137m}Ba at 350 years, while 81% of the dose for the average concentration waste comes from ^{241}Am and 18% from ^{137m}Ba.

The doses at the mud pit are about 15 times those at the shale shaker at 100 years but are negligible except for the maximum concentration, maximum volume case (100 mrem). This dose is equal to the limit for non-radiation workers from all radiation sources (100 mrem y^{-1}). However, the probability of both a maximum concentration and maximum volume event occurring simultaneously at 100 years is low.

Table 4-4. External Radiation Dose to Worker at Shale Shaker from RH-TRU Waste (Millirem - Committed Effective Dose)

Drum Loading	100 years		350 years	
	Dose	Comment	Dose	Comment
Mean Conc. - Mean Vol	2.8×10^{-2}	91% ^{137m}Ba, 9% ^{241}Am	1.9×10^{-3}	88% ^{241}Am, 6% ^{239}Pu
Mean Conc. - Max Vol	1.3×10^{-1}	91% ^{137m}Ba, 9% ^{241}Am	8.9×10^{-3}	88% ^{241}Am, 6% ^{239}Pu
Max Conc. - Max Vol	6.5×10^{0}	99% ^{137m}Ba	2.6×10^{-2}	75% ^{137m}Ba, 19% ^{239}Pu

Table 4-5. External Radiation Dose to Worker at Mud Pit from RH-TRU Waste (Millirem - Committed Effective Dose)

Drum Loading	100 years		350 years	
	Dose	Comment	Dose	Comment
Mean Conc. - Mean Volume	4.2×10^{-1}	97% ^{137m}Ba	7.1×10^{-3}	80% ^{241}Am, 18% ^{137m}Ba
Mean Conc. - Max Volume	1.9×10^{0}	97% ^{137m}Ba	3.3×10^{-2}	80% ^{241}Am, 18% ^{137m}Ba
Max Conc. - Max Volume	1.0×10^{2}	99% ^{137m}Ba	3.2×10^{-1}	98% ^{137m}Ba

4.2.3 Inhalation Doses

Calculated inhalation doses to workers are shown in Table 4-6. Inhalation doses at 100 years are about 9 times the external doses at the mud pit for average concentration RH-TRU wastes and about 5% higher for the maximum concentration. Over 99% of the inhalation dose is due to transuranics and decreases very little with time. For example the calculated dose at 10,000 years is 38% of the 100-year dose for average concentration waste and 60% for the maximum concentration waste. Thus, penetration of an RH-TRU canister will be of concern for the inhalation pathway throughout the regulatory period. Details of the inhalation calculations are presented in Appendix A.4.

The doses for average concentration wastes are less than typical U. S. dose limits for non-occupational workers. There is a reasonable chance of penetrating an RH-TRU canister during 10,000 years. For the 46.8 boreholes km^{-2} drilling rate used in the CCA there is a 50% probability of at least one hit and a 3% probability of 3 or more hits. The doses for the maximum concentration waste stream are significant for non-occupational doses. This waste stream (only 0.34% of the total) has a probability of about 0.002 of being intercepted at least once during the 10,000 year period. Probabilities greater than 0.001 are required by 40 CFR Part 191 to be included in the CCDF.

Table 4-6. Inhalation Dose to Worker at Drilling Rig from RH-TRU Wastes (Millirem - Committed Effective Dose)

Year	Mean Concentration			Maximum Concentration	
	Mean Vol	Max Vol	Comment	Max Vol	Comment
100	4.0	18.0	41% ^{239}Pu, 36% ^{241}Am	110	64% ^{239}Pu, 32% ^{240}Pu
350	3.4	16.0	48% ^{239}Pu, 28% ^{241}Am	100	67% ^{239}Pu, 33% ^{240}Pu
700	2.9	14.0	55% ^{239}Pu, 26% ^{240}Pu	100	68% ^{239}Pu, 32% ^{240}Pu
1,000	2.7	12.0	59% ^{239}Pu, 28% ^{240}Pu	100	68% ^{239}Pu, 32% ^{240}Pu
5,000	1.9	8.8	74% ^{239}Pu, 26% ^{240}Pu	82	75% ^{239}Pu, 25% ^{240}Pu
10,000	1.5	7.0	81% ^{239}Pu, 19% ^{240}Pu	65	81% ^{239}Pu, 19% ^{240}Pu

5. CALCULATED DOSES TO RESIDENT FARMER

5.1 Doses from CH-TRU

5.1.1 Inhalation Dose

The calculated inhalation radiation dose to a resident farmer located 800 m in the prevailing wind direction from the mud pit is shown in Table 5-1. Radionuclides resuspended from a dried mud pit are the source of this inhalation dose. The long-term resuspension rate, dispersion factor, deposition rate, and annual inhalation rate assumed are discussed in Appendix B.1.

Inhalation doses received by the resident farmer in a year are only 57% of those received by the worker in 80 hours at the drilling rig. This is due to a much higher χ/Q factor and resuspension rate for the worker dose calculations.

These inhalation doses are significant throughout the 10,000 year regulatory period. For a 17-curie release (5% probability of occurring during the regulatory period) the dose is about 120 mrem y^{-1}. The probability of a resident farmer being located 800 m away in the prevailing down wind direction is less than 1.0. Inhalation doses at the WNW Site boundary would be 8.3 mrem y^{-1} and at James Ranch (2.5 miles WSW of the repository and presently occupied) the dose would be about 1.9 mrem y^{1} for a 17-curie release.

Table 5-1. Inhalation Dose to Resident Farmer from CH-TRU Waste
(Millirem - Annual Committed Effective Dose)

Year	Mean Concentration			Maximum Concentration		
	Mean Vol	Max Vol	Comment	Mean Vol	Max Vol	Comment
100	21.0	110	36% ^{238}Pu, 35% ^{239}Pu	130	670	90% ^{238}Pu, 8% ^{239}Pu
350	20.0	100	57% ^{239}Pu, 20% ^{241}Am	56	280	61% ^{239}Pu, 26% ^{241}Am
700	16.0	82	68% ^{239}Pu, 17% ^{240}Pu	49	250	68% ^{239}Pu, 17% ^{241}Am
1,000	15.0	76	73% ^{239}Pu, 18% ^{240}Pu	46	230	73% ^{239}Pu, 15% ^{240}Pu
5,000	12.0	58	85% ^{239}Pu, 15% ^{240}Pu	34	170	87% ^{239}Pu, 13% ^{240}Pu
10,000	9.6	48	89% ^{239}Pu, 11% ^{240}Pu	28	140	90% ^{239}Pu, 10% ^{240}Pu

5.1.2 External Radiation Dose

The annual external radiation dose to the resident farmer from a one year deposition of CH-TRU radionuclides at the farm was calculated as described in appendix B.2.

Calculated radiation doses at 100 years and 350 years were always less than 0.01 mrem y^{1}. Since these doses were negligible compared to those from inhalation, they were not calculated for later intrusion times.

Exposure from immersion is also negligible.

5.1.3 Inhalation Dose from Deposited Radionuclides

The annual inhalation dose the resident farmer would receive from resuspension of CH-TRU radionuclides deposited about his residence during the previous year was calculated. The dirt mass loading approach described in Appendix A.4 was used. Key assumptions were: (1) all inhaled dirt was from the top $2x10^{-4}$ m of soil and the deposited radionuclides were in this volume; (2) the average outside air concentration was 65 μg m^{3} of soil; and (3) the same 5100 m^{3} annual effective inhalation rate was used.

calculation is in Appendix B.3. WIPP site specific data were used for the amount of feed consumed per day by cattle. However, three other key parameter values (fraction of deposition retained on crops, weathering rate constant, and the kilograms per meter square of forage) had to be estimated from literature that is not specific to natural, arid rangeland.

Calculated doses from the direct deposition pathway at 100 years for the maximum concentration-maximum volume CH-TRU waste scenario totaled only 0.023 mrem y^{-1}. The dose from the soil to crop pathway is negligible (less than 0.1% of the dose from direct deposition). Doses were not calculated for later times.

5.2 Doses from RH-TRU

5.2.1 Inhalation Dose

The calculated inhalation dose to a resident farmer from RH-TRU wastes is shown in Table 5-2. These doses are only about 10%-25% of those from CH-TRU.

5.2.2 External Radiation Dose

The annual external radiation dose to the resident farmer from one year deposition of RH-TRU radionuclides at the farm was calculated as described in Appendix B.2. Calculated radiation doses at 100 years were only 0.08 mrem y^{1} for the maximum concentration-maximum volume case. At 350 years the maximum dose was less than 0.001 mrem y^{1}. These doses are negligible and were not calculated for later times.

Table 5-2. Inhalation Dose to Resident Farmer from RH-TRU Waste
(Millirem - Annual Committed Effective Dose)

Year	Mean Concentration			Maximum Concentration	
	Mean Vol	Max Vol	Comment	Max Vol	Comment
100	2.2	10.0	41% ^{239}Pu, 37% ^{241}Am	62	64% ^{239}Pu, 32% ^{240}Pu
350	1.9	8.8	48% ^{239}Pu, 28% ^{241}Am	58	67% ^{239}Pu, 32% ^{240}Pu
700	1.6	7.6	55% ^{239}Pu, 26% ^{240}Pu	57	68% ^{239}Pu, 32% ^{240}Pu
1,000	1.5	7.0	60% ^{239}Pu, 28% ^{240}Pu	56	68% ^{239}Pu, 32% ^{240}Pu
5,000	1.1	5.0	75% ^{239}Pu, 25% ^{240}Pu	46	75% ^{239}Pu, 25% ^{240}Pu
10,000	0.85	3.9	81% ^{239}Pu, 19% ^{240}Pu	36	81% ^{239}Pu, 19% ^{240}Pu

5.2.3 Inhalation Dose from Deposited Radionuclides

The annual inhalation dose the resident farmer would receive from resuspension of RH-TRU radionuclides deposited on the farm during the previous year was calculated using the dust mass loading approach and the same assumptions as for CH-TRU.

This dose was about 0.2 mrem y^1 per year for the maximum concentration-maximum volume case at 100 years (0.3% of the inhalation dose due to resuspension from the mud pit). This dose is negligible and doses were not calculated for later times.

5.2.4 Dose from Ingestion of Contaminated Dirt

Calculated doses from ingestion of RH-TRU contaminated dirt decreased from 0.22 mrem y^{-1} at 100 years to 0.11 $mrem^{-1}$ at 10,000 years (maximum concentration-maximum volume case). These values are negligible and were not tabulated.

5.2.5 Dose from Crops

No dose was assumed to occur from ingestion of contaminated crops.

5.2.6 Dose from Ingestion of Beef

The dose from ingestion of beef in the maximum concentration-maximum volume RH-TRU scenario at 100 years was 0.60 mrem y^{-1}. Approximately 94% of the dose came from ^{137}Cs and 5% from ^{90}Sr. Doses were not calculated for later times.

6. CALCULATED DOSES FOR SCENARIOS II & III

6.1 Scenario II, Resident Non-Farmer

The resident non-farmer in this scenario is assumed to live in a house located at the edge of the mud pit from Scenario I. He receives radiation doses from inhalation, ingestion of dirt and external radiation only during actual residence. Calculation assumptions are given in Appendix C.

This Scenario is considered bounding because it is improbable that a person would be residing at the edge of a radiologically contaminated mud pit shortly after exploratory drilling had taken place. However, higher doses could be calculated by assuming the resident spends some period of time outdoors and also has a vegetable garden as in Scenario III.

6.1.1 Dose from CH-TRU

Calculated inhalation, ingestion, and external doses from CH-TRU releases to the surface for the six intrusion times are given in Table 6-1 for the mean concentration-mean volume and maximum concentration-maximum volume cases. This captures the range of possible doses. The doses are relatively high; in all cases greater than 100 mrem y^{1} and in the highest case exceeding the limit for occupational workers. However, these doses are not acutely hazardous and unless continued for a number of years would not be expected to significantly increase the incidence of cancer in the resident non-farmer.

6.1.2 Dose From RH-TRU

Doses to the resident-farmer from RH-TRU are shown in Table 6-2 for 100 years, 350 years, and 10,000 years. Calculations were not performed for the other intrusion times because the primary interest in RH-TRU is during the early years. The total calculated dose at 350 years and 10,000 years is only 10% to 25% of that from CH-TRU. The external dose at 100 years for the maximum concentration-maximum volume case (28 rem y^{1}) is very high. However, the probability of intersecting a maximum concentration RH-TRU canister at about 100 years is low. This external dose decreases (with the 30-year half-life of $^{137}Cs + ^{137m}Ba$) to 2.8 rem y^{-1} at 200 years and 0.27 rem y^{-1} at 300 years.

Table 6-1. CH-TRU Dose to Resident Non-Farmer-Scenario II
(Rem - Annual Committed Effective Dose)

Mean Concentration - Mean Volume					Max Concentration - Max Volume			
Year	Inhalation	Ingestion	External	Total	Inhalation	Ingestion	External	Total
100	0.18	0.19	.012	0.38	5.8	6.5	0.038	12.0
350	0.16	0.18	.012	0.35	2.2	2.5	0.21	4.4
700	0.13	0.14	.0068	0.28	2.0	2.2	0.12	4.3
1,000	0.12	0.13	.0042	0.26	1.8	2.0	0.074	3.9
5,000	0.087	0.096	.00016	0.18	1.4	1.5	0.0025	2.9
10,000	0.050	0.084	.00014	0.13	1.1	1.3	0.0021	2.4

Table 6-2. RH-TRU Dose to Resident Non-Farmer - Scenario II
(Rem - Annual Committed Effective Dose)

Year	Mean Concentration - Mean Volume				Max Concentration - Max Volume			
	Inhalation	Ingestion	External	Total	Inhalation	Ingestion	External	Total
100	0.018	0.020	0.11	0.15	0.49	0.63	28.0	29.0
350	0.015	0.017	0.0019	0.034	0.47	0.51	0.084	1.1
10,000	0.0068	0.0076	0.000012	0.014	0.30	0.33	0.00053	0.62

6.2 Scenario III, Non-Resident Farmer

In Scenario III the farmer is assumed to eat 42.7 kg y^{1} of vegetables that are grown in the mud pit. The 5 cm depth of contaminated material in the mud pit is assumed to be evenly mixed with top soil in order to make the mud pit fertile. The final depth is assumed to be 15 cm. The water used for irrigation is assumed to be uncontaminated. No deposition is occurring on the crops and there is assumed to be no surface contamination from the soil. Therefore the only radionuclides in the food come through the soil-to-crop pathway. The calculation is described in Appendix C.

This scenario is also considered bounding. There is limited ground water of adequate quality in the area and there are no known vegetable gardens. However, if this scenario occurred, doses could be higher than calculated because the non-resident farmer would be subjected to radiation doses from inhalation, dirt ingestion, and external radiation during the time spent farming in the mud pit.

6.2.1 Dose from CH-TRU

Calculated doses from CH-TRU releases to the surface for the six intrusion times are given in Table 6-3 for the mean concentration-mean volume and maximum concentration-maximum volume cases. These doses are significant but are less than the Scenario II doses at all time periods.

Doses received by the non-resident farmer while working in the garden would increase these doses significantly. For example, the inhalation + dirt ingestion + external radiation dose from 100 hours of exposure to the maximum concentration-maximum volume case at 100 years is 53% of the food intake dose.

6.2.2 Dose from RH-TRU

RH-TRU doses at 100, 350, and 10,000 years are shown in Table 6-4. The maximum dose at 100 years is 2.1 times the CH-TRU dose because of the effect of ^{90}Sr and ^{137}Cs. These two fission product radionuclides contribute 96% of the dose. For other times and cases the CH-TRU doses are 3 to 11 times greater than the RH-TRU doses.

The doses received from inhalation, ingestion, and external radiation from 100 hours of exposure were 14% of the maximum food dose at 100 years and 46% at 350 years.

Table 6-3. CH-TRU Dose to Non-Resident Farmer-Scenario III
(Rem - Annual Committed Effective Dose)

Year	Mean Conc - Mean Vol	Max Conc - Max Vol
100	0.14	3.6
350	0.13	1.9
700	0.10	1.5
1,000	0.089	1.4
5,000	0.062	0.91
10,000	0.051	0.76

Table 6-4. RH-TRU Dose to Non-Resident Farmer - Scenario III
(Rem - Annual Committed Effective Dose)

Year	Mean Conc - Mean Vol	Max Conc - Max Vol
100	0.045	7.7
350	0.013	0.33
10,000	0.0046	0.20

7. COLLECTIVE DOSE

Collective dose is the summation of radiation doses received by all persons in an exposed population.

The EPA Containment Requirements (§191.13) limit the cumulative release of transuranic radionuclides to the accessible environment. These limits are based on estimated health effects from a collective dose determined from generic global modeling. There is no regulatory requirement that a collective dose from the actual site be determined from the calculated cumulative releases. DOE has not done collective dose calculations for the releases projected in the CCA.

7.1 Collective Dose from Inhalation

The calculated collective dose from inhalation to the population within 80 km (50 miles) of the WIPP Site is presented in this report. This calculation was made because it is another measure of the health implications of the cumulative releases projected in the CCA. Details of the calculation are in Appendix D.

7.2 Other Collective Doses

Collective doses from pathways other than inhalation (external, resuspension of previously deposited material, ingestion of dirt, and the food pathway) were not calculated because previous calculations for the resident farmer indicate they are much less than inhalation doses for a single year of erosion. However, these doses would persist and there could be a buildup in the environment from continued erosion of mud pits and from subsequent intrusions during the 10,000 years. So, the contribution of non-inhalation doses to the total collective dose from inhalation will not be negligible if the mud pit is not reclaimed and erosion continues for many years.

7.3 Results of Collective Dose Calculation

Results of the annual collective inhalation dose are shows in Table 7-1. A 17 Ci release value was used because this value has about a 5% probability of occurring from an intrusion in 10,000 years (see Appendix E). These values are low because of the low population density within 15 miles of the repository and the assumption that the future population will be the same as the present. The effect of distance can be seen by noting that the annual collective dose for 100,000 people residing within 50 miles of the site is only 4 times that calculated for two workers at the drilling rig.

Somewhat higher collective doses are theoretically possible for three reasons: (1) doses are assumed to occur only for a one-year period following an intrusion and only 2.3×10^{3} of the radionuclides in the mudpit are assumed to be depleted by resuspension in a year. If all of the contents were eventually depleted by resuspension the collective dose from this one 17 Ci intrusion increases by a factor of 440; (2) multiple intrusions are expected to occur during the 10,000 year regulatory period; and (3) there would be contributions from non-inhalation pathways and, because of buildup in the environment from multi-year releases, these doses will be much greater than those we have calculated for the resident farmer during the initial year.

Table 7-1. Collective Doses From Inhalation From a 17 Ci Release of Transuranic Radionuclides

Down Wind Sector	Radial Distance (miles)	Collective Dose mrem y^{-1}
SSW	2.5	17.0
NNW	7.5	11.0
SW	15.0	3.1
WSW	15.0	96.0
W	15.0	12.0
WNW	15.0	6.4
W	25.0	640.0
WNW	25.0	340.0
E	35.0	6.4
ESE	35.0	3.6
NW	45.0	490.0
NNE	45.0	24.0
NE	45.0	35.0
ENE	45.0	33.0
	Total	1700.0

8. DISCUSSION AND CONCLUSIONS

The significance of the individual doses calculated in this report are discussed relative to: (1) the potential health effects; (2) a comparison of the health effects from individual doses and the health effects suggested by cumulative releases calculated in the CCA; and (3) the proposed cleanup standards for radiologically contaminated sites.

8.1 Potential Health Effects

The possible somatic health effects of calculated doses to drilling crew members, the resident farmer, and the population can be estimated from dose to excess cancer fatality (ECF) conversion factors in BEIR IV (NAS 1988). BEIR-IV estimates there will be 1.08×10^{-3} to 2.10×10^{-3} ECFs per rad of transuranics taken into the body. This is equivalent to 5.4×10^{5} to 1.05×10^{-4} ECFs per rem of transuranics taken into the body. Doses from a 17 Ci CH-TRU release are used because there is an estimated 5% probability that an intrusion will bring this amount of radioactive material to the surface in 10,000 years. Results are shown in Table 8-1.

Table 8-1. Risk of Excess Cancer Fatality per Year of Intake[a]

Receptor	Internal Dose (Rem)	Probability of ECF[b]
Drilling Crew	0.22	$1.2\text{-}2.2 \times 10^{-5}$
Resident Farmer(I)	0.12	$0.61\text{-}1.2 \times 10^{-5}$
Resident Non-Farmer (II)	2.0	$1.4\text{-}2.0 \times 10^{-4}$
Non-Resident Farmer (III)	0.68	$3.7\text{-}6.8 \times 10^{-5}$
Collective Dose	1.7	$0.93\text{-}1.7 \times 10^{-4}$

[a] For a 17 Ci release of CH-TRU (Probability of ~ 0.05)

[b] Collective dose risk is to population of 100,000; other risks are to an individual.

These annual risks are low. However, lifetime risks could be much higher. For the 30-year exposure period suggested in U.S. EPA 1991 the cumulative risks to the resident farmer in Scenario I would be greater than 10^{-4}. For Scenarios II and III the cumulative risk would be greater than 10^{-3}. EPA typically sets limits of radiation exposure in its regulations so that lifetime risks would not exceed 10^{-3} to an individual.

The individual doses shown in Table 8-1 for the workers and resident farmers have about a 5% probability of occurring in one of the intrusions during the 10,000 year regulatory period if the projected drilling rate occurs. However, the probability that any one generation will receive similar doses is much lower.

8.2 Comparison of Health Effects

The cumulative release limits in 40 CFR Part 191 were derived from the results of generic, global modeling of the total health effects from a curie of each radionuclide that might be released into the environment. The release limits would result in an estimated 1,000 ECFs in 10,000 years for a full sized repository containing 10^8 Ci of TRU waste.

The WIPP repository is projected to have 3.44×10^6 Ci of TRU waste at the time of repository closure. This would scale to 34.4 ECFs in 10,000 years if the full allowable release occurs. The CCA calculations predicted a release of 6% of the allowable limit at a probability of 0.1. Thus, the implicit number of health effects would be 1.7 deaths in 10,000 years from a release of 17 curies.

The collective dose calculated in Table 7-1 (for a 17 Ci release) would become 1.8 person-rem per year from inhalation when the dose to the resident farmer is added. If it were assumed that all the material deposited in the mud pit was eventually resuspended and transported to the regional population the total dose from primary inhalation would be 810 person-rem. The inhalation doses from resuspension of deposited material and ingestion doses from deposited dirt would also increase by a factor of 440 if all of the contaminated material in the mud pit was eventually resuspended. Also, there would be some food pathway doses incurred.

A conservative integrated collective dose (see Appendix D) was calculated to be 3100 person-rem with calculated health effects of 0.17 to 0.31 excess cancer fatalities. This is reasonable agreement with the implicit value of 1.7 fatalities derived from 40 CFR 191 release limits.

This comparison suggests that the global, generic modeling of health effects conducted by EPA is greater than, but within an order of magnitude of, the very approximate site specific calculation performed here. This is as good agreement as can be expected.

Another implication of this comparison is that at WIPP an individual dose standard that included doses from human intrusion would provide a more stringent limit than the present cumulative release limit. For example, these calculations suggest that a dose limit for the resident farmer of 100 mrem y^{-1} at the 5% probability level would limit the allowable release to 14 Ci for a single intrusion. The cumulative release limit allowed from all intrusions in 40 CFR 191 is 344 Ci at the 0.1 probability level.

8.3 Comparison with Cleanup and Low-Level Radioactive Waste Disposal Standards

8.3.1 Cleanup Standards

Promulgated cleanup standards for contaminated sites do not exist although EPA, DOE, and NRC all have proposed rules. On-going cleanups are being addressed by these agencies on a case by case basis. Cleanup will probably be required to limit doses to an individual to 25 to 100 millirem per year. It is uncertain whether the standards will allow variances to exceed the maximum annual dose for unusual situations.

The methodology and assumptions used to calculate the maximum individual dose need to be known in order to compare with the individual dose calculations in this report. It is likely that EPA cleanup standards will follow the modeling assumptions in U. S. EPA 1989. This methodology determines the reasonable maximum exposure (RME) to an individual that is expected to occur at a site from all environmental media through all reasonable pathways. Both current and future land use is to be considered and this requires professional judgement. The

RME is to be calculated at about the 95% upper confidence level. So, the RME is intended to be a low probability exposure but not a maximum exposure.

The probabilities of the calculated individual doses would include the upper 95% confidence level probability of an RME. For example there is about a 5% probability (using PAVT assumptions) that the release due to cutting + cavings + spallings will be ≥17 Ci from a CH-TRU intrusion. The calculated doses from Table 8-1 are 220 mrem y^{1} for drilling rig workers and 120 mrem y^{1} for the resident farmer for a 17 Ci release.

This comparison leads to the preliminary conclusion that the predicted doses at WIPP would not meet the expected cleanup standards for contaminated sites. It could be argued that human intrusion should not be considered in a cleanup standard. However, EPA has required that human intrusion at WIPP be considered an expected event. Even if doses to the intruders were excluded (because of their negligence in causing the intrusion) the estimated resident farmer inhalation dose would still exceed any likely clean up standard.

8.3.2 Low-Level Waste Disposal

Dose limits used by NRC in the Final Rulemaking on Land Disposal of Low-Level Radioactive Waste (10 CFR Part 61) could also be compared to these calculated individual doses. These regulations limit doses after closure to 25 mrem to the whole body. NRC also limits concentrations of low level waste so that an inadvertent intruder would not receive a dose greater than 500 mrem y^{-1}. They considered a human intruder-construction scenario (where an intruder builds a house on the disposal site) and intruder-agriculture scenario (where an intruder lives on and consumes food grown on the disposal facility) (U. S. NRC 1981). These scenarios are more comparable to Scenarios II and III than to Scenario I. Doses in Scenarios II and III from a 17 Ci release exceed the 500 mrem y^{-1} dose used by the NRC.

8.3.3 Applicability to WIPP

The results of these comparisons to other standards lead to two questions:

(1) Should WIPP individual doses be less than the maximum allowable doses for remediated sites and/or low-level radioactive waste disposal standards?

(2) If the answer to question one is yes, how can doses be reduced?

The answer to question one should be more of a philosophical and/or societal decision than a technical one. Both the NAS and the EPA have considered this issue. The NAS in their Yucca Mountain high-level waste disposal report on the technical bases for standards recommended that doses to individuals from waste brought to the surface by human intrusion should not be considered (NAS 1995). EPA considered using an individual dose standard in early drafts of the 40 CFR Part 191 rule and concluded that this was not a practical way to regulate high-level and transuranic waste disposal.

Reduction of individual doses could be addressed as an As Low as Reasonably Achievable (ALARA) issue with practical remedial measures being incorporated into a repository design even though not required by standards. ALARA designs, such as waste treatment, would be an assurance requirement as defined in 40 CFR Part 191.14.

In the original CCA submittal to the EPA, DOE assumed that passive institutional controls were 99% effective in deterring human intrusion during the period of 100 to 700 years after repository closure. EPA has, in effect, rejected the efficacy of passive institutional controls (markers, monuments, and records) in their review of the CCA by requiring DOE to assume the full drilling rate after 100 years in the Performance Assessment Verification Test (PAVT) calculations. EPA has allowed 100% credit against human intrusion for active institutional controls during the first 100 years after repository closure.

Waste form modification has the potential to reduce the amount of material brought to the surface from cavings, spallings, and direct brine releases. For example, the amount of cavings is dependent on the shear strength of the waste. If the CH-TRU waste was treated to increase the shear strength so that the present mean volume (0.60 m^3) was never exceeded there would be no intrusion after 154 years where the total release to the surface exceeded 14 Ci (see Table 3-1). This condition would reduce the inhalation dose to the resident farmer to $<$ 100 mrem y^1.

8.4 Summary and Conclusions

There are inherent uncertainties in estimating repository conditions, human actions and individual doses at WIPP over a 10,000 year period. With this caveat, the following conclusions are reached:

- Calculated doses to drilling crew members and the resident farmer exceeded annual dose limits for occupational radiation workers only for the low probability Scenarios II and III at the 100 year intrusion time.

- Calculated doses to drilling crew members and the resident farmer exceeded 100 mrem y^{-1} at the 95% probability level. This is greater than the limits allowed in other standards regulating radioactive material, waste disposal and contaminated site cleanup.

- Calculated doses to the resident non-farmer and the non-resident farmer (for the 95% probability release) are greater than the 500 mrem y^{1} value NRC used for similar scenarios in establishing low-level radioactive waste concentration limits in 10 CFR Part 61.

- Health effects predicted from a very preliminary integrated collective dose calculation are less than but within an order-of-magnitude of the health effects implied from 40 CFR Part 191 for the amounts released in the CCA.

- An individual dose limit of 100 mrem y^{1} (at the 95% probability level) to the resident farmer at WIPP would be about an order-of-magnitude more restrictive than the cumulative release limit in 40 CFR 191. Releases predicted in the CCA would be less than the 100 mrem y^{-1} limit but releases predicted in the PAVT would be > 100 mrem y^{-1}.

- Since individual doses can be substantial, DOE should use "As Low as Reasonably Achievable" (ALARA) designs (such as treating the Waste) to limit these doses.

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10. ACRONYMS

ALARA	As Low as Reasonably Achievable
BIR	Baseline Inventory Report
CCA	Compliance Certification Application
CCDF	Complementary Cumulative Distribution Function
CH	Contact-Handled
DOE	U. S. Department of Energy
ECF	Excess Cancer Fatality
EEG	Environmental Evaluation Group
EPA	U. S. Environmental Protection Agency
FEIS	Final Environmental Impact Statement
NAS	National Academy of Sciences
NAS/NRC	National Academy of Sciences/National Research Council
NRC	U. S. Nuclear Regulatory Commission
OECD/IAEA	Organization for Economic Cooperation and Development/International Atomic Energy Agency
PA	Performance Assessment
PAVT	Performance Assessment Verification Test
RFETS	Rocky Flats Environmental Technology Site
RH	Remote Handled
RME	Reasonable Maximum Exposure
SNL	Sandia National Laboratories
TRU	Transuranic Waste
WIPP	Waste Isolation Pilot Plant

APPENDIX A
CALCULATION OF DOSES TO DRILLERS

A.1 DRILLING ASSUMPTIONS

The necessary drilling assumptions are taken from values used in the CCA when available. The parameter values necessary for calculations are:

(1) drill bit diameter - 0.311 m (12.25 inch)

(2) drilling fluid flow rate - 0.0309 $m^3 s^{-1}$ (490 gallons per minute)

(3) penetration rate in salt - 0.00254 m s^{-1} (30 feet per hour)

(4) total depth of drilling - 2100 m

(5) size of mud pit - 4300 m^2

The first three parameter values are from the CCA. The depth of drilling is the approximate depth of most oil exploratory holes around WIPP. The mud pit size is the average of those examined around WIPP in a 1984 study (Reith 1984). This sized pit will give a total cuttings plus cavings depth of about 5 or 6 cm in a dried mud pit. Thus, it is reasonable to use external dose coefficients for soil contaminated to a depth of 5 cm (U. S. EPA 1993).

The drilling fluid flow rate and penetration rate in salt are needed to calculate the time that a driller is exposed to contaminated cuttings at the shale shaker and the concentration of radionuclides in the drilling fluid. It is assumed that the contaminated cuttings do not dispense in the drilling fluid as it flows to the surface (i.e. there is "plug" flow) and the radionuclides are evenly mixed in the drilling fluid flow that occurs while the waste is being penetrated.

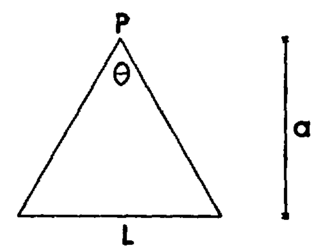
For an initial CH-TRU room height of 3.96 m, the penetration time would be 1560 seconds and the drilling fluid volume is 48.1 m^3.

For the RH-TRU canister with an assumed effective depth of penetration of 0.7 m, the penetration time would be 275 seconds. The drilling fluid volume during this time would be 8.50 m^3.

A.2 DOSE FROM DRILLING MUD AT THE SHALE SHAKER

A worker is assumed to be standing near the shale shaker during the period of time that contaminated drilling fluid is going through the shale shaker and a one-meter-wide trough to the mud pit. The depth of fluid in the trough is assumed to be 7 cm (equivalent to a soil depth of about 5 cm). The exposure can be treated as a ten-meter-long line source of exposure with the receptor being one meter away. The diagram and equation are shown below:

$$\phi = \frac{S\theta}{4\pi a}$$



Where S is source of strength in photon s^{-1} cm^{-1} of length (L)

ϕ = flux in photons cm^{-2} s^{-1} at P
a = distance to point of interest from line source (100 cm)
L = length of trough at shale shaker (10 m)
θ = subtended angle in radians (2.75)

The value of S can then be determined from the number of Curies of a radionuclide brought to the surface:

$$S = 7x10^{-4} \frac{m^3 cm^{-1} (Ci)i}{m^3 \text{ of contaminated drilling fluid}}$$

When constant terms are combined the expression for ϕ becomes: $\phi = 6.66 \times 10^{3} (Ci)_i f_i$ for RH-TRU and $\phi = 1.18 \times 10^{3} (Ci)_i f_i$ for CH-TRU, where f_i is the fraction of disintegrations of radionuclide i that emit gamma radiation of a specific energy.

The absorption of gamma radiation in the drilling fluid for the important radionuclides was determined from the ratio of dose coefficients for exposure to contaminated ground surface (Table III.3 in U. S. EPA 1993) to the coefficients for exposure to soil contaminated to a depth of 5 cm (Table III.5). It is necessary to convert the Bq m^{-3} of contaminated soil to Bq m^{-2} of surface area to make this comparison. The dose rate from this calculated flux of a specific energy photon can be obtained from standard curves. (e.g. U. S. DHEW 1970, pg. 132).

A.3 WORKER DOSE AT THE MUD PIT

The radionuclides entering the mud pit are assumed to be evenly mixed in 5 cm of solids that have settled from the drilling mud. The total volume of cuttings was estimated to be about 225 m^3. The concentration (in Bq m^{-3}) of each radionuclide was then calculated and the dose coefficients (in Sv $Bq^{-1} s^{-1} m^2$) from Table III.3 in U. S. EPA 1993 were used to obtain the effective dose for each radionuclide.

The dose rates for all the radionuclides shown in Tables 3-1 and 3-2 were included in the total dose rate unless it was obvious that their contribution to the total would be negligible. Those radionuclides that contribute more than about 0.2% of the final dose are included in Tables 4-2 and 4-5.

The dose rates in Table III.3 assume the 65 m x 65 m mud pit is an infinite isotropic plane source. A worker standing on the edge of this pit can be assumed to be exposed to one-half of an infinite source and receive one-half of the dose calculated for the center of the mud pit. A residence time of 12 hours was assumed for the duration of the drilling operation.

It is assumed that workers near the drilling rig (100 m from the center of the mud pit) do not receive any direct radiation from the mud pit because (with an assumption that elevation of the mud pit is not lower than the drill rig) a low berm will obstruct the line-of-sight at a point one meter above the surface. This is not the most conservative assumption, since direct radiation could occur.

There will be scattered radiation (skyshine) from the atmosphere and perhaps other objects near the mud pit that will reach workers near the drilling rig. The magnitude of scattered radiation was not calculated.

A.4 INHALATION DOSES TO WORKERS

Workers are assumed to be at the drilling rig for 80 hours after the mud pit has dried. They will be exposed to resuspended material from the dried mud pit during those hours when the drilling rig is downwind. The resuspension factor will be higher initially and the high value of 6.0×10^{-5} m^{-1} from La Plante 1995 was chosen. When coupled with a deposition velocity of 1.8×10^{3} from Parks 1992 one obtains a resuspension rate of 1.1×10^{7} s^{-1}. This resuspension rate is applicable primarily to surface contamination and not to the 5 cm depth of contaminated material in the mud pit. An effective depth of 2×10^{4} m was assumed based on discussions contained in Linsley 1978. This is 4×10^{3} of the depth of the contaminated material in the mud pit. All resuspended material is assumed to be respirable.

The relative concentration from atmospheric dispersion was calculated from expression (3) in U. S. NRC 1982:

$$\frac{\chi}{Q} = \frac{f}{u\pi\sigma_z\sigma_y}$$

where:

χ/Q = relative concentration in s m^{-3}.
f = frequency that wind blows toward receptor
u = average windspeed, m s^{-1}
σ_z = vertical plume spread in m
σ_y = lateral plume spread in m

The values of σ_y and σ_z are functions of atmospheric stability class and distance from the source. They are obtained from Figures 1, 2, and 3 (for 100 m distance) in U. S. NRC 1982 for Stability Category D. Stability Category D (neutral) was selected because it is more prevalent in daytime hours than the more severe inversion conditions (Categories E and F). Wind direction frequency and mean velocity were determined from Tables H-43 and Appendix H, Annex 1, Table 2 of

U. S. DOE 1980. Winds blow from the southeast 37% of the time in July and the mean wind speed was calculated as 3.5 m s^{-1}. It was assumed that the worker inhales 1.4 m^3 h^{-1} during his 40-hour work week.

These combinations of numbers lead to a χ/Q value of 6 x 10^4 s m^{-3} and an inhaled volume of 112 m^3 during the 80 hours of exposure. Radiation doses to workers from inhalation were obtained by multiplying the Becquerels of each radionuclide inhaled by the dose conversion factors (Sv Bq^{-1}) from Eckerman 1988, Table 2.1. The results are shown in Tables 4-3 and 4-6.

A.4.1 Alternate Inhalation Calculation

A common method of estimating inhalation doses for onsite exposure is to assume that the dirt in the air contains the same specific activity as is present in the contaminated soil. Typically, average values for dirt mass loading in the air are used. For example, U. S. EPA 1994 uses 1.5 μg m^{-3} for suburban areas and values as high as 200 μg m^{-3} for rural residential areas. Values for WIPP have been reported as 77.7 μg m^{-3} for 24 hour average and 18.47 μg m^{-3} for annual arithmetic mean (U. S. DOE 1980). This approach was not used in Scenario I for occupational exposure because the contamination was not considered to be onsite. However, it is possible to calculate the concentration of contaminated dirt inhaled from the mud pit as a comparison. For the worker inhalation, this value is about 130 μg m^{-3}. Dirt loadings would typically be higher during the work day when wind speeds are greater and atmospheric stability is less. Therefore, this comparison suggests that the method used gives results that are roughly the same as those obtained using the mass loading approach. The mass loading approach was used to evaluate inhalation from resuspension of deposited contamination at the resident farm and also for inhalation in Scenario II (the resident non-farmer case).

A.4.2 Reclamation of Mud Pits

Mud pits are often reclaimed (i.e. covered with earth) in the area around WIPP. Reith 1984 reports that 70% of the pits surveyed had been reclaimed. There was no definition of what the reclamation criteria was nor any indication of the elapsed time between drilling these wells (an average of 7+ years before the survey) and reclaiming the mud pits. Reclaiming a mud pit is not likely to significantly decrease the dose from resuspension during the first year because the resuspension rate is greatly increased during remediation. For example, Woolfolk 1982 used a resuspension rate 9 times that used in this report for 32 hours during pit remediation. These higher values would have caused several times the worker inhalation dose calculated in this report. Inhalation doses to the resident farmer from a reclaimed mud pit would have been lower in the first year if reclamation occurred within 9 months after drilling.

Reclamation of mud pits was not assumed in this report because: (1) it may not occur at all or soon after drilling; (2) it would lead to higher calculated loses to workers and (3) it might not significantly decrease the dose to the resident farmer in the first year.

APPENDIX B
CALCULATION OF DOSES TO THE RESIDENT FARMER

B.1 INHALATION DOSE

The atmospheric dispersion approach used for the resident farmer inhalation dose was similar to that used to calculate worker inhalation doses. However, an average annual χ/Q value of 5×10^{-5} s m^{-3} from WIPP Site data was used.

The median resuspension factor (1×10^{-5} m^{-1}) from La Plante 1995 was used. When coupled with a 1.8×10^{-3} m s^{-1} deposition velocity, the resuspension rate becomes 1.8×10^{-8} s^{-1} of the top 2×10^{-4} m of contaminated soil.

The fraction of resuspended particles remaining in the plume (0.91) at 800 m was taken from Figure 2 in Regulatory Guide 1.111 (U. S. NRC 1977a) and the deposition rate (6.0×10^{-5} m^{-1}) was taken from Figure 6. This value was used in determining the amounts deposited per square meter for external radiation and crop/soil contamination. Inhalation doses from radionuclides deposited at the farm were evaluated. Assumptions that exposure is: (1) 73% indoors at an inhalation rate of 0.63 m^3 h^{-1}; (2) concentration indoors is 0.5 of that outdoors; (3) outdoor breathing rate is 1.4 m^3 h^{-1}; and (4) residence of 350 days per year leads to an annual equivalent inhalation rate of 5,100 m^3 (La Plante 1995).

B.2 EXTERNAL RADIATION DOSE

The deposition rate of radionuclides from the contaminated plume was taken as 6.0×10^{-5} m^{-1} of the 91% remaining in the plume at 800 m. This value, when divided by the arc length of a 22.5° sector (314 m), gives the fraction of the plume depleted per square meter (1.74×10^{-7} m^{-2}).

The amount deposited per square meter in a year is the product of the fraction of each radionuclide in the pit that is eroded per year (2.3×10^{3}), the fraction of the time the wind is blowing toward the resident farm (0.188), the amount remaining in the plume at 800 m, and the fraction deposited per square meter. The amount deposited per square meter is 7.42×10^{11} of the total quantity of radionuclides in the pit. Dose rates for exposure to contaminated ground surface were taken from Table III.3 in U. S. EPA 1993. The dose calculated per year was adjusted by a factor of 0.635 to account for the assumption that the farmer spends 73% of his time indoors, where the exposure rate is 0.5 of that outside.

B.3 CONCENTRATIONS IN CROPS, FEED, MILK AND MEAT

B.3.1 Calculations of Concentrations

The basic equation used for calculating concentrations of radionuclides in forage crops, leafy vegetables, and other produce is equation C-5 in Regulatory Guide 1.109 (U. S. NRC 1977b):

$$C_{iv} = d_i \left[\frac{r[1-\exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{B_{iv}[1-\exp(-\lambda_i t_b)]}{P \lambda_i} \right] \exp(-\lambda_i t_h) \qquad (B-1)$$

where:

C_{iv} = concentration of radionuclide i in crops, Bq kg^{-1}

d_i = deposition, Bq m^{-2} per year

r = fraction of deposition retained on crops (used 0.2; the median value from La Plante 1995 is 0.4, but about one-half of surface at WIPP is bare ground (U. S. DOE 1981).

λ_{Ei} = effective removal constant, a combination of λ_w, (weathering rate constant) and λ_i (radiological decay). λ_i, is ignored here with long-lived radionuclides. Value used is 6.50 y^{-1}. This is lowest value reported in Till 1983, and appears most logical for an arid area.

Y_v = agricultural productivity in kg (wet weight) m^{-2}, used 0.1 in Case I and 2.0 for all crops in Case III. The Case I value is estimated because no data are available for WIPP. The Case III value is from U. S. NRC 1977b.

t_e = length of time crops are exposed to contamination during growing season. Used 1,440 hours (0.16 year) from U. S. NRC 1977b.

B_{iv} = concentration factor for uptake of radionuclide i from soil by edible portions of crops, in Bq kg^{-1} (wet weight) of crops per Bq kg^{-1} dry soil. Volumes for each element are from La Plante 1995 or U. S. NRC 1977b and are shown in Table B-1.

P = effective surface density of soil for 15 cm deep plow layer. Used 215 kg m^2 from Parks 1992.

λ_i = radiological decay constant for radionuclide i.

t_b = build-up time for concentration in soil; used a value of one year.

t_h = hold up time before food is consumed. Ignored here because time is short relative to half-life of these radionuclides.

Table B-1. Soil to Crop and Crop to Milk and Food Concentration Factors

Element	Concentration Ratio		Transfer Coefficient
	Other Vegetables	Grain	Beef
Am	4.7×10^{-4}	2.2×10^{-5}	4.0×10^{-5}
Cs	7.2×10^{-2}	1.0×10^{-2}	5.0×10^{-2}
Pu	2.3×10^{-4}	8.6×10^{-6}	1.0×10^{-5}
Sr	1.7×10^{-2}	1.7×10^{-2}	6.0×10^{-4}

Strontium values from U. S. NRC 1977b. Remaining values from La Plante 1995

The radionuclide concentration in beef is determined by:

$$C_{ib} = F_{ib} C_{iv} Q_f e^{-\lambda t_f} \qquad \text{(B-2)}$$

F_{ib} = average fraction of the animals' daily intake for radionuclide i that appears in each kilogram of flesh in days kg^{-1}. Values taken from La Plante 1995 or U. S. NRC 1977b.

Q_f = amount of feed consumed per day. 7.6 kg d^{-1} of air-dry contaminated range was used from U. S. DOE 1981.

t_f = hold up time before beef is consumed by humans. Ignored here because of long half-lives of radionuclides.

B.3.2 Intake and Doses Received by Resident Farmer

The quantity of radionuclides taken into the body of the resident farmer in a year can be obtained by multiplying the calculated concentrations of crops, milk, and meat by reasonable assumptions of the annual intake of locally grown foods. Values for produce are from U. S. EPA 1991. Meat consumption is assumed to be 75% of the value recommended in U. S. NRC 1977b for an average adult (95 kg y^{-1}).

Table B-2. Annual Quantity of Food Ingested by Resident Farmer

Food Item	Kg/y	Comment
all produce	42.7	assumed to be all other vegetables
beef	71.2	75% of total beef intake
soil	0.035	

APPENDIX C
CALCULATION FOR SCENARIOS II & III

C.1 SCENARIO II, RESIDENT-NON FARMER

The resident non-farmer is assumed to live in a house on the edge of the dried mud pit from scenario I and occupies the house 73% of the time (6400 hours y^1). While indoors the resident non-farmer inhales contaminated air, ingests some contaminated dirt and is exposed to external radiation. Time outside the house is minimal and no dose is assumed.

The indoor inhalation rate is assumed to be 0.63 m^3 h^{-1} and the air has a particulate concentration of 32.5 μg m^{-3} (one-half of outdoor air). Only one-half of the airborne particulates come from the mud pit. The amount of mud pit dirt inhaled is 0.0655 g y^1. Dirt ingestion is assumed to occur at a rate of 0.0175 kg y^1 (one-half the rate assumed for the resident farmer because of the lack of outside activity). Also, only one-half of the ingested dirt comes from the mud pit. Thus, the amount of mud pit dirt ingested is 0.00875 kg y^1.

External radiation is received for 6400 hours per year at one-half of the unshielded dose rate that exists outdoors at the edge of the mud pit. This is equivalent to 267 times the dose received by a drill crew member in 12 hours.

C.2 SCENARIO III, NON-RESIDENT FARMER

Since only the soil-to-crop pathway is being considered in Scenario III, the first term of the general expression for determining the concentration of radionuclides in crops (the foliage deposition term) shown in Equation B-1 can be deleted. Also, the expression can be further simplified because continuous deposition is not occurring. The term simplifies to:

$$C_{iv} = \frac{dB_{iv}}{\rho}$$

where d is expressed in Bq m^{-2}, B_{iv} is Bq kg^{-1} crops/Bq kg^{-1} soil, and ρ is density of soil (215 kg m^{-2}). When the area of the mud pit and conversion from curies to Becquerels is included this term becomes:

$$C_{iv} = 4.00 \times 10^{4} (\text{Curies in mud pit})_t \, B_{iv}$$

At any time t.

This expression can be multiplied by the 42.7 kg y^{1} of vegetable consumption to obtain the Bq y^{-1} intake. This value can then be modified by the Sv Bq^{1} conversion factor to obtain the annual dose.

APPENDIX D
COLLECTIVE DOSE CALCULATION

D.1 ANNUAL COLLECTIVE DOSE FROM INHALATION

The collective dose was calculated only for inhalation of material resuspended from the mud pit.

The same mud pit resuspension rate from the top 2×10^{4} m was assumed (1.8×10^{-8} s^{-1}). The 1990 population distribution in 22.5° sectors at various distances out to 80 km was taken from U. S. DOE 1996b, Table F-10 (see Table D-1). Long-term average χ/Q values were taken from U. S. DOE 1980, Table H-49 (see Table D-2). An equivalent annual breathing intake volume of 5100 m^3 was used. Depletion of the plume at the various distances was also included in the calculation. The dose conversion factor for ^{239}Pu and ^{240}Pu (1.16×10^{-4} Sv Bq^{-1}) was used for all transuranic radionuclides (this overstates the dose calculation from ^{238}Pu by 9% and underestimates the dose from ^{241}Am by 3%).

The combination of these factors leads to a dose for each sector(s) and radial distance (d) of:

$$D_{sd} = 1.58 \ Ci \ (dep_d) \frac{\chi}{Q}_{sd} P_{sd}$$

where: D_{sd} is annual collective dose in Sv y^{1}
Ci is total curies of transuranics in mud pit
χ/Q_{sd} is dispersion expression for given sector and distance, s m^{3}
dep_d is fraction of transported radionuclides remaining in plume at distance d.
P_{sd} is 1990 population for given sector and distance.

D.2 POSSIBLE INTEGRATED COLLECTIVE DOSE

A conservative, very approximate integrated collective dose can be calculated as follows. Assume that the inhalation doses from deposited radionuclides and ingestion doses from deposited dirt build up to a value of 440 times the initial year values (which were 0.35% and 0.30% of the primary inhalation dose at the end of one year). Also, that there is assumed to be no depletion of these deposited radionuclides and radioactive decay is neglected. The resident population (which is assumed to be stable) is exposed to primary and secondary inhalation and ingestion during the

440 year buildup period. Secondary inhalation plus ingestion will continue for an additional 440 years while the deposited material is being lost from resuspension. These are conservative assumptions because all of the material in the mud pit would not be resuspendable or respirable. However, non conservative assumptions are: (1) neglecting food pathway doses from the >200 km^2 of irrigated agriculture within the 80 km radius; and (2) neglecting doses from all pathways at distances beyond 80 km.

The original dose is 1.8 person-rem per year when the resident-farmer's dose is included. The dose at 440 years is 3.9 times the initial dose (7.1 person-rem per year). For the next 440 years the annual dose drops from 5.3 person-rem per year to zero. With the simplifying assumption that build up and decay of the annual dose rate is linear an integrated collective dose can be calculated. This leads to a total dose of:

$$\textit{Total Collective Dose} = 440\left[\frac{1.8+7.1}{2} + \frac{5.3}{2}\right] = 3{,}100\ \textit{person rem}$$

This collective dose would result in 0.17 to 0.31 ECFs.

Table D-1. 1990 Population Distribution Within 80 Kilometers (50 Miles) of WIPP

Direction	Distance (miles)										
	0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50	Total
S	0	0	0	0	0	0	3	2	46	20	71
SSW	[a]9	0	0	0	0	0	0	2	43	8	62
SW	0	0	0	0	0	0	37	57	0	5	99
WSW	0	0	0	0	0	0	1,622	191	57	62	1,932
W	0	0	0	0	0	0	138	25,291	197	3	25,629
WNW	0	0	0	0	0	0	38	5,765	242	63	6,108
NW	0	0	0	0	0	0	6	7	14	12,401	12,428
NNW	0	0	0	0	0	9	4	66	104	56	239
N	0	0	0	0	0	0	3	0	63	12	78
NNE	0	0	0	0	0	0	4	3	122	7,353	7,482
NE	0	0	0	0	0	0	0	11	37	9,115	9,163
ENE	0	0	0	0	0	0	0	10	282	30,877	31,169
E	0	0	0	0	0	0	6	5	2,982	19	3,012
ESE	0	0	0	0	0	0	0	16	2,173	97	2,286
SE	0	0	0	0	0	0	0	0	15	20	35
SSE	0	0	0	0	0	1	3	14	5	73	96
TOTAL	9	0	0	0	0	10	1,864	31,440	6,382	60,184	99,889

Source: U. S. DOE 1996b Table F-10

a. Location of these 9 persons is an error. Should be SSW, 2-3 miles.

Table D-2. WIPP Site Long-Term Average X/Q Calculations
(Period of Record, June 1977 through May 1979)

Downwind Sector	X/Q (sec/m^3) at downwind distance (miles)					
	2.5	7.5	15.0	25.0	35.0	45.0
N	$1.0x10^{-6}$	$1.8x10^{-7}$	$3.9x10^{-8}$	$1.7x10^{-8}$	$7.2x10^{-9}$	$8.4x10^{-9}$
NNE	$5.7x10^{-7}$	$9.0x10^{-8}$	$2.0x10^{-8}$	$9.0x10^{-9}$	$3.3x10^{-9}$	2.6x10
NE	$6.8x10^{-7}$	$1.1x10^{-7}$	$3.0x10^{-8}$	$1.2x10^{-8}$	$4.4x10^{-9}$	$3.1x10^{-8}$
ENE	$5.4x10^{-7}$	$5.7x10^{-8}$	$1.5x10^{-8}$	$5.4x10^{-9}$	$1.1x10^{-9}$	$8.6x10^{-10}$
E	$4.8x10^{-7}$	$4.8x10^{-7}$	$1.2x10^{-8}$	$4.2x10^{-9}$	$1.3x10^{-9}$	$1.1x10^{-9}$
ESE	$4.5x10^{-7}$	$4.2x10^{-8}$	$1.1x10^{-9}$	$4.7x10^{-9}$	$1.0x10^{-9}$	$7.3x10^{-10}$
SE	$4.3x10^{-7}$	$5.3x10^{-8}$	$1.6x10^{-8}$	$6.2x10^{-9}$	$1.7x10^{-9}$	$1.5x10^{-9}$
SSE	$5.2x10^{-7}$	$7.7x10^{-8}$	$2.3x10^{-8}$	$3.6x10^{-7}$[a]	$4.0x10^{-9}$	$2.7x10^{-9}$
S	$6.4x10^{-7}$	$1.1x10^{-7}$	$3.0x10^{-8}$	$1.0x10^{-8}$	$6.0x10^{-9}$	$3.2x10^{-9}$
SSW	$8.5x10^{-7}$	$1.4x10^{-7}$	$3.9x10^{-8}$	$1.8x10^{-8}$	$6.8x10^{-9}$	$5.2x10^{-9}$
SW	$9.6x10^{-7}$	$1.6x10^{-7}$	$5.0x10^{-8}$	$1.8x10^{-8}$	$8.8x10^{-9}$	$4.8x10^{-9}$
WSW	$8.5x10^{-7}$	$1.4x10^{-7}$	$3.5x10^{-8}$	$1.2x10^{-8}$	$5.6x10^{-9}$	$3.1x10^{-9}$
W	$1.2x10^{-6}$	$1.9x10^{-7}$	$5.0x10^{-8}$	$1.7x10^{-8}$	$7.8x10^{-9}$	$4.5x10^{-9}$
WNW	$2.5x10^{-6}$	$3.8x10^{-7}$	$1.0x10^{-7}$	$3.9x10^{-8}$	$1.9x10^{-8}$	$9.5x10^{-9}$
NW	$3.2x10^{-6}$	$7.6x10^{-7}$	$2.5x10^{-7}$	$1.1x10^{-7}$	$5.5x10^{-8}$	$3.2x10^{-8}$
NNW	$3.0x10^{-6}$	$5.8x10^{-7}$	$2.5x10^{-7}$	$7.8x10^{-8}$	$4.6x10^{-8}$	$2.6x10^{-8}$

Source: adapted from U. S. DOE 1980, Table H-48

[a] This value appears to be a typographical error

APPENDIX E
DETERMINATION OF 95% UPPER CONFIDENCE LEVEL RELEASE TO SURFACE

The Reasonable Maximum Exposure (RME) used by EPA for cleanup standard calculations is defined as approximately the 95% upper confidence level. This could also be expressed as the dose that is expected to be exceeded only 5% of the time. It is desireable to estimate the approximate number of curies brought to the surface at WIPP at the 95% upper confidence level to cleanup standards.

With all the complicated probabilistic calculations in the CCA it is not easy to arrive at probabilistic values for curies released to the surface. The procedure used here was:

(1) The cumulative probability distribution of curies brought to the surface from 104 intrusions calculated in Futures 1 through 20 of Vector #1 in the CCA was determined. All Vector #1 intrusions had a cuttings and cavings volume of 0.9046 m^3. Similarly, the distribution of curies from 110 intrusions in Futures 1 through 20 in Vector #2 was determined and combined with the distribution from Vector #1. It was necessary to adjust the Vector #2 values (which were for a volume of 0.6164 m^3) by a factor of 1.468 to be consistent with the cuttings & cavings volume of Vector #1. When a constant volume is used the variations in number of curies released is due to the random sampling of radionuclide concentrations in the 569 waste streams, to the time of intrusion, and to the variable releases from spallings and direct brine releases. It is reasonable to assume that this curie distribution which was obtained from 214 data points will be the same for all volumes of cutting and cavings. The values for any intrusion i and cumulative probability, p can be scaled directly by the relationship:

$$Curies_{i,P} = Curies_{.9046P}\left[\frac{Volume\ i}{.9046}\right]$$

(2) Volumes calculated from the PAVT were used rather than the CCA volumes for two reasons: (a) they are believed to be more realistic because of changes in several parameter values; and (b) the distribution of volumes released were more readily available. Thirty six percent of the PAVT volume releases exceeded 1.0 m^3 and 16% exceeded 2.0 m^3.

(3) There are expected to be 5.84 intrusions into the waste repository during the 10,000 year regulatory period. So, the percentile level that has a 5% chance of occurring in one of the intrusions is a value higher than 95% in the curie release distribution. This percentile level can be approximated by the relationship:

$1 - P^n$ = probability that at least one of n occurrences will be ≥ the cumulative probability value, P.

For n = 5.84 and the probability of 0.05, the minimum value of P is 0.991 (or 1-P = 0.009)

(4) The volume of each individual intrusion was taken from PAVT 1997 Figure 5.1 beginning from the highest value (3.95 m^3). An estimated curie release limit (e.g. 17 curies) was divided by the volume scaling factor to determine the appropriate curie level on the Vector #1 + #2 cumulative probability plot. This value would be 3.89 Ci for the 3.95 m^3 volume. From this curie level the related probability of the 17 Ci release from the one borehole could be determined. This probability is multiplied by 0.01 because this intrusion volume is only one of 100 volumes. The probabilities are summed for each intrusion volume to determine the total probability that the given release level will occur.

The probability of a 17 Ci release from a single intrusion was found to be 0.00999 or 0.0100. The probability that this large a release would appear in one of the 5.84 expected intrusions in the repository was calculated to be 0.057. So the calculated release is slightly less than the 95% value used for the RME.

The uncertainties in calculating a 95% upper confidence level for WIPP releases are significant and not quantifiable. Similar uncertainties would be expected to occur in calculations at most cleanup sites.

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