

EEG-72

**A COMPARISON OF THE RISKS FROM THE
HAZARDOUS WASTE AND RADIOACTIVE
WASTE PORTIONS OF THE WIPP INVENTORY**

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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 long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the compliance of the generator sites 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

FOREWORD	iii
EEG STAFF	iv
ACKNOWLEDGMENTS	v
EXECUTIVE SUMMARY	ix
1. INTRODUCTION	1
2. INVENTORY	4
2.1 Volatile Organic Compounds	4
2.2 Hazardous Metals	5
2.3 Radionuclides	6
3. RISKS FROM ROUTINE OPERATIONS	7
3.1 National Academy of Sciences Comparison	7
3.2 Routine VOC Exposures and Risks	9
3.2.1 Underground Worker	10
3.2.2 Surface Worker	16
3.2.3 Public Resident at Site Boundary	16
3.3 External Radiation	18
3.3.1 Assumed External Radiation Exposure	18
3.3.2 Risks from External Radiation Exposure	19
3.4 Comparison of VOC and External Radiation Risk	19
3.4.1 Comparison of Risks to Workers	21
3.4.2 Risks to Resident at WIPP Site Boundary	21
4. RISKS FROM ACCIDENTS AND LONG-TERM RELEASES	22
4.1 Hazardous Metals Inventory	22
4.2 Operational Accidents	23
4.2.1 Relative Risks from Operational Accidents	23
4.2.2 Absolute Risks from Operational Accidents	24
4.2.3 Risks to Public from Operational Accidents	25
4.3 Long-Term Releases to Surface	26
4.3.1 Relative Risks from Long-Term Releases	26
4.3.2 Absolute Risks from Long-Term Releases	28

5. SUMMARY AND CONCLUSIONS	30
5.1 Summary	30
5.2 Discussion	31
5.2.1 Perspective on Risk	31
5.2.2 Probabilistic Considerations	32
5.3 Conclusions	33
6. ACRONYMS & ABBREVIATIONS	AC-1
7. REFERENCES	R-1
APPENDIX A Calculation of Amount of Material Inhaled in an	
Operational Accident Involving a Radioactive Release	A-1
LIST OF EEG REPORTS	RL-1

LIST OF TABLES

Table 3-1	Lifetime Carcinogenic Risks from Routine VOC Emissions to the Underground Worker	13
Table 3-2	Hazard Quotient and Hazard Index from Non-Carcinogenic VOC Exposures to Underground Workers	15
Table 3-3	Lifetime Carcinogenic Risks to the Surface Worker from Routine VOC Emissions	17
Table 3-4	Lifetime Carcinogenic Risks to WIPP Site Boundary Resident from Routine VOC Emissions	18
Table 3-5	Comparison of VOC and Radiation Cancer Risks	20
Table 4-1	Hazardous Metals-Average Quantities and Risks Per Waste Drum	23
Table 4-2	Rem/Curie Value for WIPP TRU Waste Inventory	24
Table 4-3	Risks to Workers from Radionuclides and Hazardous Wastes Released During Operational Accidents	25
Table 4-4	Risks of Radionuclides and Hazardous Waste Brought to the Surface from Human Intrusion at 1,000 Years	29
Table 5-1	Average Radiological to Hazardous Waste ECF Risks	30
Table A-1	Risks from VOCs in Drum Headspace Volume	A-4

LIST OF FIGURES

Figure 1-1	WIPP Site Location in Southeastern New Mexico	2
Figure 3-1	Three-dimensional View of the Waste Isolation Pilot Plant	8
Figure 3-2	Waste Emplacement Process	11
Figure 4-1	Schematic Representation of a Rotary Drilling Operation Penetrating the Repository	27

EXECUTIVE SUMMARY

The carcinogenic and non-carcinogenic risks from the radioactive and hazardous waste constituents of the transuranic waste to be emplaced at the Waste Isolation Pilot Plant (WIPP) have been estimated. Risks from routine operations, accidents during the operational period, and long-term releases following human intrusion were evaluated separately. The risk from the hazardous waste component was compared numerically to that of the radioactive component.

Six major conclusions resulted from this study:

1. Risks are low in all cases. Lifetime carcinogenic risks are expected to be about 1×10^{-3} for workers and about 1×10^{-8} for members of the public.
2. The expected radiological carcinogenic risks to workers from routine operations and from operational accidents were at least four orders of magnitude greater than the carcinogenic risk from the hazardous waste constituents. Under maximum conditions, the radiological risks are more than two orders of magnitude greater than the hazardous waste risks.
3. During routine operations, a member of the public residing at the WIPP Site Boundary would receive a very low carcinogenic risk (less than 10^{-8} lifetime) from Volatile Organic Compounds (VOCs) and no radiological risk. The radiological risk to a member of the public from average operational accidents is over five orders of magnitude greater than the hazardous waste risk.
4. Radionuclide annual risks to a resident farmer from average releases to the surface following human intrusion 1000 years after WIPP closure are one order of magnitude greater than total risks from VOCs. These long-term risks are two orders of magnitude lower than risks during the operational period and are less likely to occur.
5. Non-carcinogenic risks from VOCs during operation are less than 2% of the Hazard Index and are not important relative to the carcinogenic risks.

6. The evaluations confirmed the intuitive assumption that radiological risk from WIPP wastes are much greater than the risks from hazardous wastes.

1. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) Project is located in Southeastern New Mexico (See Figure 1-1). WIPP has been constructed by the U.S. Department of Energy (DOE) to provide permanent disposal of long-lived transuranic (TRU) waste from the U.S. defense activities and programs. The facility must comply with 40 CFR 191, Subpart A during the period when radioactive waste are being emplaced (operating period) and with 40 CFR 191, Subpart B and 40 CFR 194 for long-term disposal. The U.S. Environmental Protection Agency (EPA) has concluded that WIPP meets the requirements of 40 CFR 191 and 194 and made a Certification Decision in May 1998 (EPA 1998). The repository begin receiving radioactive TRU wastes in March 1999.

The DOE estimates that 60% of the TRU wastes are “mixed wastes” that is, they contain hazardous wastes (HW) that are regulated under the Resource Conservation and Recovery Act (RCRA). Regulation of WIPP under RCRA has been delegated by EPA to the New Mexico Environment Department (NMED). The NMED will regulate WIPP under the State of New Mexico Hazardous Waste Management Regulations [20 NMAC 4.1]. Draft permits were issued in May and November 1998, but due to the requirements for comments and public hearings, a final permit is not expected before September 1999. Mixed TRU waste cannot be brought to WIPP until a final Hazardous Waste Permit has been issued unless interim status is invoked by DOE.

The delay in opening WIPP for TRU mixed wastes has raised the issue of whether there are any health and safety needs for RCRA regulation of a facility that is regulated for radioactive waste. Two general claims have been made: (1) the HW toxicity is so much less than the radioactive material toxicity that it could be ignored; and (2) adequate control of the radioactive material should automatically provide similar control for the HW.

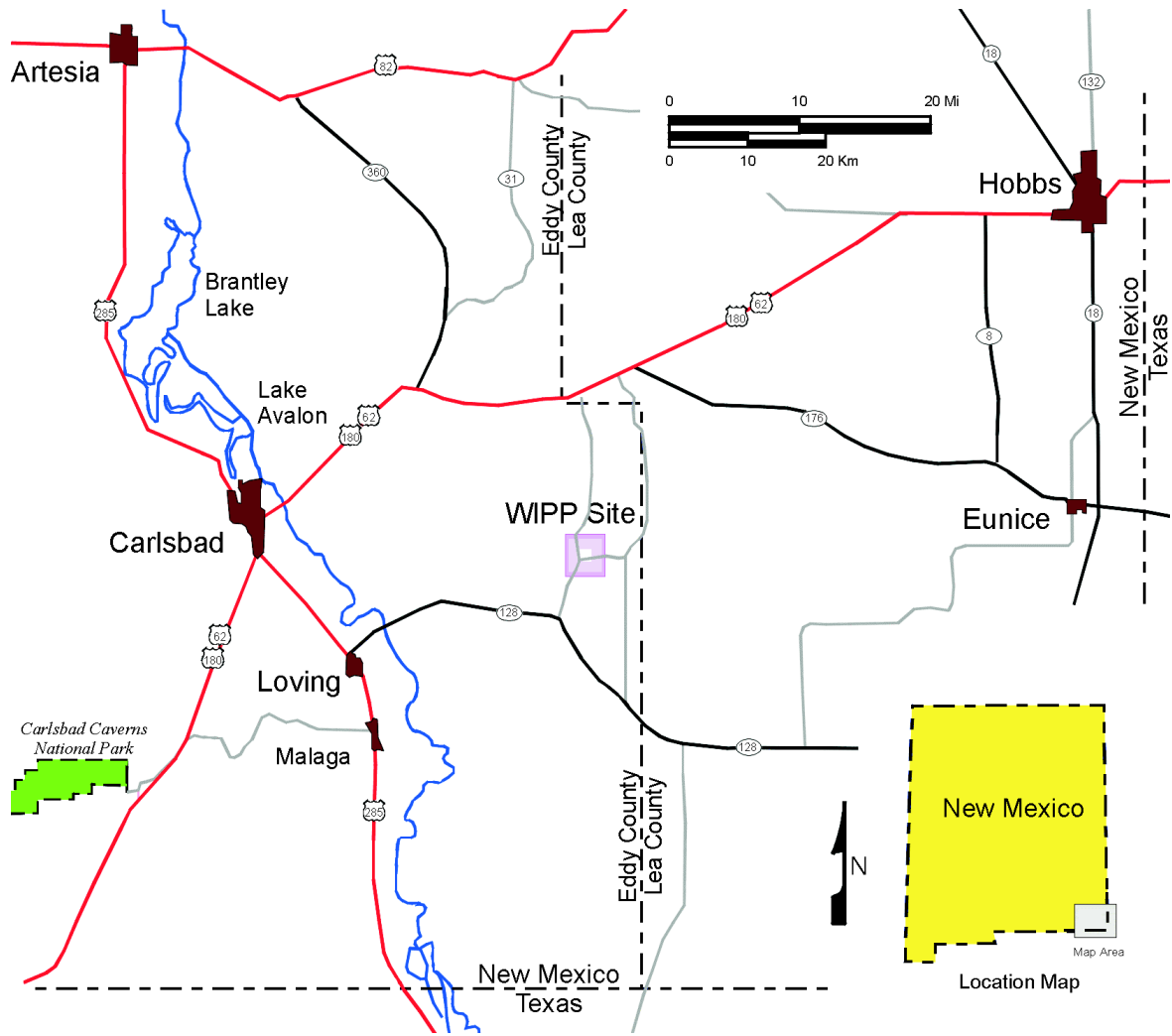


Figure 1-1. WIPP Site Location in Southeastern New Mexico

However, with the exception of a simple comparison of the average TRU waste toxicity to the average Volatile Organic Compound (VOC) toxicity by the National Academy of Sciences (NAS) WIPP Committee, no analyses have been published that evaluated these claims (NAS 1996).

This report evaluated the first claim about relative toxicity by quantitatively comparing the radiological and non-radiological risks to workers and the public from exposures during routine operation of the WIPP facility over the 35 y period of waste emplacement. Risks from accidents during the emplacement period and from long-term releases after repository closure are also evaluated. Carcinogenic risks are expressed in probabilities of an excess cancer fatality (ECF). Non-carcinogenic risks are compared to a Hazard Index (HI). Calculations of exposure scenarios are deterministic rather than probabilistic. The analyses are limited to Contact-Handled TRU (CH-TRU) wastes because there are no hazardous waste data on Remote-Handled TRU (RH-TRU) waste and releases from operational and long-term accidents have had very little evaluation. The exclusion of RH-TRU waste is not expected to significantly affect the comparison because it contains only 4% of the waste volume, less than 14% of the total radioactivity (at the time of emplacement), and less than 1% of the long-lived radioactivity.

2. INVENTORY

The origins of the inventories used for VOCs, hazardous metals, and TRU radionuclides are described separately below.

2.1 Volatile Organic Compounds

DOE reports headspace gas analyses for 28 VOC constituents from 930 drums of CH-TRU waste in Appendix C2 of their RCRA Part B Permit Application (the Application, DOE 1997a). Drums from all 12 Waste Matrix Code Groups (WMCGs) were sampled. Average values for each VOC constituent for each WMCG were calculated. In most cases average concentrations were heavily influenced by a few high values and were much higher than median values. The relative volume of each WMCG (Table 3-5, Baseline Inventory Report, Revision 1, DOE 1995) was used as a weighing factor, and the weighted average concentration for each VOC constituent was calculated by:

$$\bar{x} = \sum_{j=1}^{j=t} w_j x_j, \quad (1)$$

where

\bar{x} = weighted average concentration (ppmv)

x_j = average for WMCG_j

w_j = weighing factor for WMCG_j

t = number of WMCGs

The calculations for average values of several VOCs in each WMCG, the WMCG weighing factors, and the weighted average values of the key VOCs were checked. Our calculated values agreed with the values reported by the DOE.

DOE (Appendix D13 of the Application) performed a VOC screening to determine the most significant carcinogenic and non-carcinogenic VOCs that needed to be regulated. The weighted average head space gas concentration was multiplied by the unit risk factor (URF) for each carcinogenic VOC and by the chronic reference dose for exposure (R_fC) to non-carcinogenic VOCs to obtain a calculated score. The VOCs that included 99% of the total calculated score in each category were retained for regulation.

The Environmental Evaluation Group (EEG) agreed with the calculation for carcinogenic VOCs. However, EPA's Integrated Risk Information System (IRIS) database (EPA 1999) does not consider 1,1,1-Trichloroethane to be a carcinogen, so it was not included in our calculations. The six retained VOCs (in order of decreasing risk) were carbon tetrachloride (76%), 1,1,2,2-Tetrachloroethane (8%), Chloroform, 1,1-Dichloroethylene, 1, 2-Dichloroethane, and Methylene Chloride. Values of the headspace gas concentrations for the carcinogenic VOCs are given in Table 3-1.

DOE reported that two non-carcinogens (Chlorobenzene and Toluene) comprised over 99% of the calculated risk. An error was found in DOE's Methyl Ethyl Ketone calculated score, and it should have been included. Also, 1,1,1-Trichloroethane needs to be added. The corrected percent of total risk values are 50% for Chlorobenzene, 43% for 1,1,1-Trichloroethane, 3% for Methyl Ethyl Ketone, and 3% for Toluene.

2.2 Hazardous Metals

DOE presented no information on hazardous metal concentrations or quantities in either the Application or the Final No-Migration Variance Petition. They justified this lack of data by stating: "The DOE presents several implicit assumptions related to demonstrating no-migration for liquid-phase hazardous constituents, but believes that explicitly defining a source term for liquid-phase hazardous constituents is inappropriate, given the available information" (page 8-36 of DOE 1996a). DOE's position basically is that only VOC releases are credible under

assumptions required by RCRA regulation. The NMED has not objected to this determination nor asked for hazardous metal data.

To compare the total risks from HW, it is necessary to consider the risks from hazardous metals due to accidental releases during operation and for long-term releases including human intrusion, even if the risks are not required by RCRA regulations. The possible migration of hazardous metals would be similar to evaluations of TRU radionuclide migration required under 40 CFR Part 191 (EPA 1993).

Some data are available on a few of the RCRA-regulated hazardous metals. These data are reported in the WIPP Disposal Phase Final Supplemental Environmental Impact Statement (SEIS-II, DOE 1997b) and in the WIPP Safety Analysis Report (SAR, DOE 1999). The average concentrations of beryllium, cadmium, lead, and mercury are shown in Chapter 4.

2.3 Radionuclides

Three different aspects of the radionuclide inventory are important when comparing radionuclide risks with those of VOCs or hazardous metals. These are: (1) the concentration of TRU radioactivity at time of emplacement; (2) the concentration of TRU radioactivity at the time of repository closure; and (3) the external radiation received from waste containers.

The radionuclide inventory at time of emplacement is taken from Draft Appendix WCA (Table WCA-5) of the Compliance Certification Application (CCA, DOE 1996b). The inventory at time of closure is taken from Table 4-8 of the CCA. Values for the significant radionuclides are given in Chapter 4.

The external radiation dose received by workers at WIPP from routine surface and underground operations is assumed to be 18.2 person-rem/y at the full emplacement rate of 6500 m³/y (DOE 1999). The external dose rates from a stack of emplaced drums in the underground were assumed to be 15.6 mrem/h at 2 to 6 feet and 7.2 mrem/h at 6 to 10 feet distance (DOE 1988).

3. RISKS FROM ROUTINE OPERATIONS

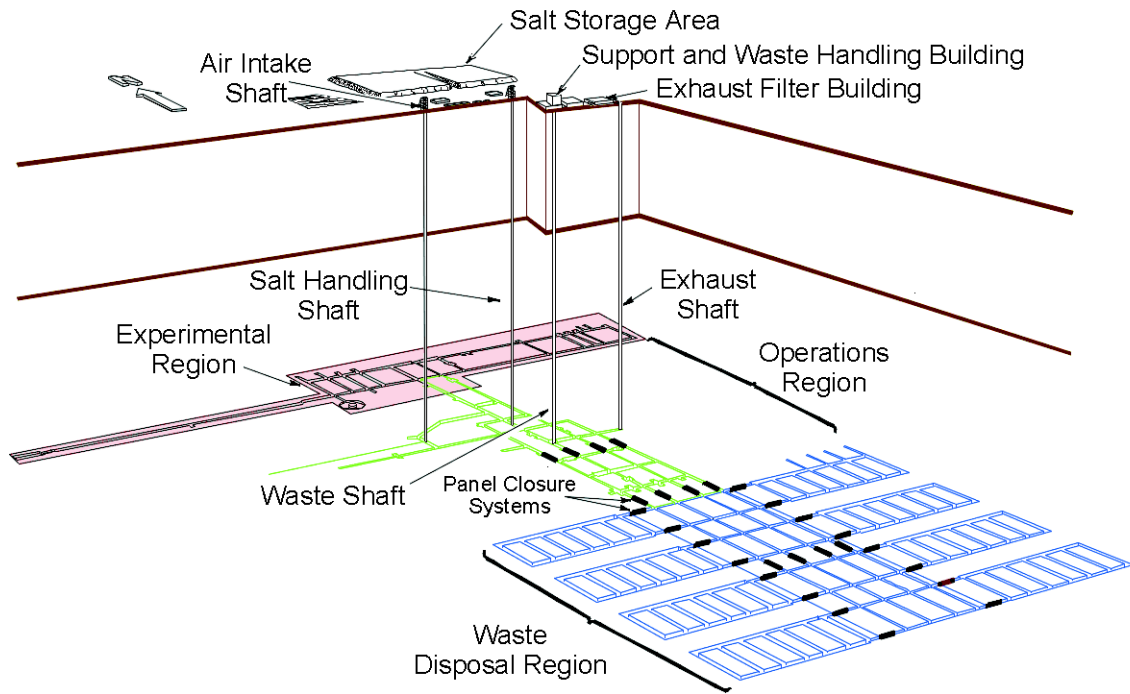
Exposures from HWs and radioactive TRU waste could occur from: (1) routine operations during the 35 y emplacement period; (2) accidents that occur during this operational period; and (3) human intrusion events that occur after the repository is sealed. This report will evaluate the three categories separately for both the hazardous and the radioactive constituents. Values are those used by DOE and/or the State of New Mexico unless stated otherwise. Uncertainties exist in these risk calculations from four sets of estimates and assumptions: (1) inventories of HW and TRU waste in the waste containers; (2) assumptions about the release mechanisms from containers; (3) the location and duration of individual exposure; and (4) the risk coefficients used for both radiation and chemical effects. No attempt will be made to quantify these uncertainties.

A three-dimensional view of the WIPP is shown in Figure 3-1 with a general description of waste panels and rooms. Waste containers are unloaded from TRUPACT-II packages inside the Waste Handling Building (WHB) where exhaust ventilation air passes through high energy particulate aerosol (HEPA) filters. The waste is transported down the waste shaft which originates from within the WHB. Emplacement in waste rooms is always upstream of the ventilation air flow. Ventilation air exhausts through the exhaust shaft and is unfiltered during normal operation.

3.1 National Academy of Sciences Comparison

The NAS (Box 2.1, NAS 1996) compared the risk from inhalation of all the VOCs in 1 m³ of waste with that from inhaling all the radionuclides in 1 m³ of waste.

The NAS reported that the inhalation of VOCs in 1 m³ of waste would lead to a risk of 9×10^{-5} excess cancer fatalities (ECFs). The average TRU waste concentration of 20 Ci/m³ leads to a radionuclide inhalation risk of about 6.5×10^5 or about 7×10^9 greater than the VOC risk.



Note: For illustrative purposes only.
Not to scale.

Figure 3-1. The WIPP facility includes surface support buildings, a waste handling building, four shafts, and the mined underground operations area. The repository is located approximately 658 m (2150 ft) below the surface, within the Salado Formation, a Permian sequence of bedded salt with minor amounts of anhydrite and clay. The excavations are accessible from the surface by four vertical shafts. Only one of the eight panels has been excavated to date. Each panel consists of seven rectangular rooms, 10 m wide and 91 m long, separated by 30.5 m wide pillars. Source: DOE 1996b

The NAS calculation is computationally correct but not an appropriate comparison. The VOCs will escape the containers through filtered vents during routine operations and will be inhaled by anyone downstream from the source. Barring an accident, no release of TRU waste or non-volatile HW from waste containers is expected.

The only expected radiation dose at the WIPP Site is from external radiation from waste containers. Persons involved in receiving, checking, transporting, and emplacing waste containers in underground disposal rooms will receive a measurable amount of radiation. The estimated risk from external radiation is compared to VOC emissions in this chapter.

3.2 Routine VOC Exposures and Risks

Routine exposure assumptions for underground workers, surface workers and the public are similar to those used in Appendix D9 of the Application. The values for the exposure concentration in the underground (ECU), the exhaust shaft concentration (ECS), air dispersion factors (ADFs) for the surface worker and the WIPP Site Boundary were determined using Appendix D9 methodology. Assumed underground ventilation air rates (35,000 ft³/min in a room and 260,000 ft³/min total) are taken from the November 1998 Draft Permit (NMED 1998).

The risks of cancer (dimensionless) from each VOC can be determined for the underground worker, the surface worker, and the resident at the site boundary from:

$$\begin{aligned} \text{Risk} &= \text{ECU (URF) } F_u \\ &= \text{ECS (ADF)}_s \text{ (URF) } F_s \\ &= \text{ECS (ADF)}_b \text{ (URF) } F_b \end{aligned}$$

where:

URF	=	the cancer unit risk factor in m ³ /μg for each VOC
F	=	the fraction of lifetime inhalation (8400m ³ /y for 70 y) that occurs in the scenario
u	=	value for underground worker
s	=	values for surface worker
b	=	values for boundary resident

The risk factors used were the same as those in Appendices D9 and D13. These values were checked with the IRIS data base to ensure the latest information was used. The considerable uncertainty in most of these risk factors is discussed in IRIS.

3.2.1 Underground Worker

The process of waste emplacement in rooms and panels is shown in Figure 3-2. A worker will normally be downstream from emplaced waste only when drums are being emplaced in the exit drift. This location will be downstream from all filled rooms. The filled rooms will have ventilation barriers; no flow of ventilation air, but some emanation of gases is assumed to occur through the barriers. This emanation from open panels will also be a source of above ground exposure. Panel seals will be emplaced after a panel is completely filled. However, it is assumed gaseous emissions will continue from all filled panels and this will be a source of exposure to persons above ground.

The underground worker is assumed to be present downwind (in the exhaust drift) from a panel of wastes where six of the seven rooms are full and have ventilation barriers. The annual amount of each VOC displaced from a room through a ventilation barrier is:

$$\frac{\text{moles}}{y} \text{VOC}_i = 0.5 \frac{\text{moles}}{\text{drum-y}} (11,571 \frac{\text{drums}}{\text{room}}) (\text{Molecular Fraction VOC}_i). \quad (2)$$

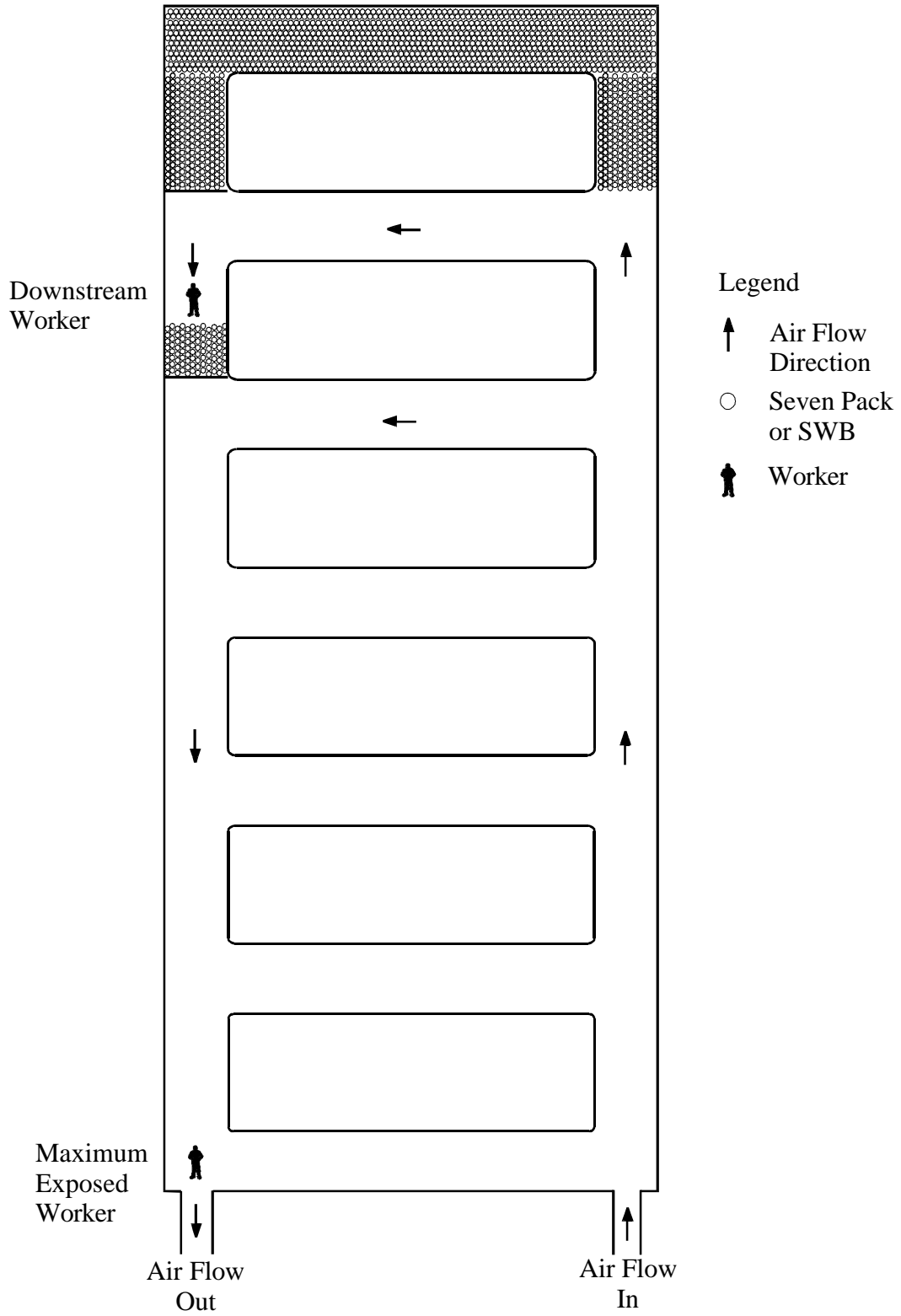


Figure 3-2. Waste Emplacement Process (Source: DOE 1999).

DOE (in Appendix D9) made two assumptions: all VOCs were displaced through the exhaust drift ventilation barrier, and the worker is present in this maximum downwind location 33 h per year for a 10 y period. DOE time-motion studies (DOE 1988) for general emplacement and for emplacement of magnesium oxide sacks (DOE 1999) estimated an exposure time of about 11.5 minutes per 7-pack for the maximum individual. This is equivalent to 148 h/worker for emplacing the 776 7-packs/y in the 133 ft. of waste rooms that is downwind from ventilation barriers. For two-shift operation the maximum individual worker would be exposed 74 h/y. However, since the worker will be exposed to an average of three closed rooms with ventilation barriers, the equivalent six room exposure time is 37 h/y. Thirty-seven hours per year for 10 years is equivalent to 7.55×10^{-4} of a worker's lifetime. The average and maximum risks for those VOCs that are carcinogenic are shown in Table 3-1. All rooms are assumed to be filled with wastes at the maximum allowed room values (Room Based Concentration Limits - RBCLs) for the maximum values and at the weighted average values for the average values. The risk from all carcinogenic VOCs is combined to give a total risk. These risks are the upper 95 percentile estimates for each VOC, and the totals may be artificially high (EPA 1989).

Risks from non-carcinogenic VOCs were also evaluated. Non-carcinogenic effects to members of the public are evaluated using a hazard quotient (HQ), defined as:

$$HQ_i = \frac{\text{average exposure concentration } VOC_i \text{ (fraction of time exposed)}}{RfC_i} \quad (3)$$

For a 10 y exposure period and 37 h/y of exposure at an inhalation rate of 1.2 m³/h the fraction of a 35 y working lifetime exposure is 1.5×10^{-3} .

Table 3-1
Lifetime Carcinogenic Risks from Routine VOC Emissions to the Underground Worker

VOC	URF ^a (m ³ /μg)	Maximum Values			Weighted Average Values		
		Room Limit ^b (ppmv)	ECU (μg/m ³)	Risk	Headspace ^c (ppmv)	ECU (μg/m ³)	Risk
Carbon Tetrachloride	1.5×10 ⁻⁵	11,475	118.0	1.3×10 ⁻⁶	375.	3.85	4.4×10 ⁻⁸
Chloroform	2.3×10 ⁻⁵	9,130	72.7	1.3×10 ⁻⁶	25.3	0.199	3.5×10 ⁻⁹
1,1-Dichloroethylene	5.0×10 ⁻⁵	5,050	32.6	1.2×10 ⁻⁶	11.5	0.0743	2.8×10 ⁻⁹
1,2-Dichloroethane	2.6×10 ⁻⁵	3,350	22.1	4.3×10 ⁻⁷	9.1	0.0601	1.2×10 ⁻⁹
Methylene Chloride	4.7×10 ⁻⁷	100,000	566.	2.0×10 ⁻⁷	368.	2.08	7.4×10 ⁻¹⁰
1,1,2,2 -Tetrachloroethane	5.8×10 ⁻⁵	2,720	30.4	1.3×10 ⁻⁶	9.4	0.105	4.6×10 ⁻⁹
Totals				5.8×10 ⁻⁶			5.6×10 ⁻⁸

^a Unit Risk Factor for carcinogens.

^b VOC room-based concentration limits (RBCLs) (NMED 1998).

^c Weighted average headspace gas concentration (Appendix C-2 of the Application).

A HI can then be calculated from the sum of HQ_i values for all VOCs (t) with non-carcinogenic effects:

$$HI = \sum_{i=1}^{i=t} HQ_i \quad (4)$$

RfC_i is the chronic reference dose for exposure by inhalation from VOC_i . For HI values of less than 1.0, adverse health effects are unlikely even to sensitive populations, and values much below 1.0 have no precise meaning. The HI is definitely not probabilistic i.e., a value of 0.01 does not imply a 1% probability of an effect. EPA allows HI values from all compounds having non-carcinogenic effects to be summed to obtain an overall HI. However, the meaning of this total HI value is uncertain because different effects are often being summed. None of the carcinogenic compounds in Table 3-1 had RfC values for non-carcinogenic effects and thus did not have to be included in the HI. HQ and HI values are given in Table 3-2. The HI for the RBCLs is less than 0.01 and thus not a cause for concern.

For occupational workers, it is more appropriate to use Occupational Safety and Health Administration (OSHA) or American Conference of Governmental Industrial Hygienists limits for a time weighted average (TWA) over an 8 hour workday. There is also another short-term limit, the Immediately Dangerous to Life or Health Limit, which is of primary concern in accident scenarios where puff releases could occur. TWA values (in mg/m^3) are also shown in Table 3-2.

The maximum exposure concentrations for individual VOCs are two to four orders of magnitude below the OSHA TWA values, and the summed total value for all VOCs is only 1.0% of allowable. Therefore, there is no concern about the underground worker approaching TWA limits.

Table 3-2
Hazard Quotient and Hazard Index from Non-Carcinogenic VOC Exposures to Underground Workers

VOC	RfC($\mu\text{g}/\text{m}^3$)	Maximum Concentrations		Weighted Average Concentrations		8 Hour TWA (mg/m^3)
		Exposure Conc. ($\mu\text{g}/\text{m}^3$)	Hazard Quotient	Exposure Conc. ($\mu\text{g}/\text{m}^3$)	Hazard Quotient	
Chlorobenzene	20	98	7.4×10^{-3}	0.094	7.1×10^{-6}	350 ^a
Toluene	400	68	2.6×10^{-4}	0.12	4.5×10^{-7}	750 ^a
Methyl Ethyl Ketone	1000	~31	4.7×10^{-5}	0.31	4.6×10^{-7}	5 ^b
1,1,1-Trichloroethane	700	420	9.0×10^{-4}	2.8	6.1×10^{-6}	1900 ^a
Totals (Hazard Index)			8.6×10^{-3}		1.4×10^{-5}	

^a American Conference of Governmental Industrial Hygiene Value.

^b OSHA value that should not be exceeded at any time.

3.2.2 Surface Worker

The surface worker is assumed to be exposed to VOC emissions from the repository exhaust shaft for 1920 h/y for a period of 10 y. The ADF is taken as 1.23×10^{-2} , and the Fs factor is 3.92×10^{-2} . All of these assumptions are identical to those in Appendix D9 of the Application.

Risks from carcinogens were calculated for a maximum condition and an average condition. The scenario assumed that VOCs would be released through ventilation barriers from eight closed panels and four closed rooms and from 9,000 drums of waste in an open room (the average condition of the repository for the last 10 years of waste emplacement). For the maximum risk, all rooms are assumed to have headspace gas concentrations at the RBCLs from Table IV.D.1 (NMED 1998). Average risk calculations assumed that all rooms were at the weighted average concentration. The calculated risks and exposures are shown in Table 3-3.

Risks to the surface worker for non-carcinogens are slightly greater than those for the underground worker because the occupancy time is 52 times longer. The HI totaled 0.014.

3.2.3 Public Resident at Site Boundary

The Maximum Individual Receptor (MIR) is assumed to be a member of the public continuously residing at the WIPP Site Boundary during the entire 35 y projected period of waste emplacement. The MIR will be exposed to both maximum and average VOC emission rates from four closed panels and six closed rooms with ventilation barriers and a full open room in the fifth panel. The maximum case assumes that all rooms are at the RBCLs and the average case uses the weighted average concentrations of headspace gas. The lifetime risks are shown in Table 3-4.

Table 3-3
Lifetime Carcinogenic Risks to the Surface Worker from Routine VOC Emissions

VOC	Maximum Risk		Average Risk	
	ECS($\mu\text{g}/\text{m}^3$)	Risk ^a	ECS($\mu\text{g}/\text{m}^3$)	Risk ^a
Carbon Tetrachloride	316.	2.3×10^{-6}	10.3	7.5×10^{-8}
Chloroform	205.	2.3×10^{-6}	0.57	6.3×10^{-9}
1,1-Dichloroethylene	94.4	2.3×10^{-6}	0.22	5.2×10^{-9}
1,2-Dichloroethane	62.0	7.8×10^{-7}	0.17	2.1×10^{-9}
Methylene Chloride	1680.	3.8×10^{-7}	6.2	1.4×10^{-9}
1,1,2,2-Tetrachloroethane	81.7	2.3×10^{-6}	0.28	7.9×10^{-9}
Totals		1.0×10^{-5}		9.7×10^{-8}

^a Values rounded from three significant figures.

The source term assumptions for the average case could be non-conservative because the assumptions do not consider a room with RBCL VOC concentrations. However, the chance of having a room containing concentrations close to the maximum for all VOCs is slight; if it occurred, this room would be receiving wastes for only about 6 months in the 35 y exposure period. Another non-conservatism would be if the actual weighted average concentrations in the final inventory turn out to be greater than now estimated. Offsetting the non-conservatism are two other assumptions: a resident will be located continuously at the site boundary location with the highest ADFs and sealed panels will not pressurize and contain some of the VOC emissions. The maximum case should be a plausible upper limit risk.

Table 3-4
Lifetime Carcinogenic Risks to WIPP
Site Boundary Resident from Routine VOC Emissions

VOC	Maximum Risk		Average Risk	
	ECS ($\mu\text{g}/\text{m}^3$)	Risk ^a	ECS($\mu\text{g}/\text{m}^3$)	Risk ^a
Carbon Tetrachloride	240	2.2×10^{-7}	8.0	7.2×10^{-9}
Chloroform	160	2.2×10^{-7}	0.45	6.2×10^{-10}
1,1-Dichloroethylene	75	2.2×10^{-7}	0.17	5.1×10^{-10}
1,2-Dichloroethane	49	7.6×10^{-8}	0.13	2.1×10^{-10}
Methylene Chloride	1340	3.8×10^{-8}	5.0	1.4×10^{-10}
1,1,2,2-Tetrachloroethane	64	2.2×10^{-7}	0.22	7.6×10^{-10}
Totals		1.0×10^{-6}		9.4×10^{-9}

^a Values rounded from three significant figures.

3.3 External Radiation

3.3.1 Assumed External Radiation Exposure

The SAR assumes that external radiation doses would be 18.2 person-rem/y for about 20 waste handlers and an unspecified number of radiation technicians but does not attempt to estimate maximum or average individual doses. Since we have calculated VOC intakes and risks to individuals rather than populations, it is appropriate to develop external radiation dose assumptions for both the maximum and the average exposed individual.

Data from waste processing and handling activities at the DOE generating and storage sites suggest that the projections in the SAR for WIPP are too large (DOE 1998). The overall average exposure for all workers where there is measurable exposure is 0.059 rem/y. Also, less than 1% of all exposures are greater than 0.5 rem/y. For the predominately TRU waste activities at the Idaho National Engineering and Environmental Laboratory (INEEL) and Los Alamos National Laboratory (LANL), the averages are 0.048 and 0.040 rem/y. At INEEL, 11.4% of all exposures

were between 0.1 and 0.25 rem/y, and none were >0.25 rem/y. At LANL 8.9% were in the 0.1-0.25 rem/y range, 2.2% in the 0.25-0.50 rem/y range, and none were >0.5 rem/y.

Although the regulatory limit is 5 rem/y, the maximum permitted dose (administrative limit) for a radiation worker at WIPP is 1.0 rem/y. Assuming that DOE will not allow the administrative limit to be exceeded, the maximum plausible exposure for an individual is taken as 1.0 rem/y for a 10 y period.

The average dose to the maximally exposed worker is assumed to be 0.25 rem/y for a 10 y period. This dose is likely to approximate the upper 95% probability level for all exposed waste management workers.

3.3.2 Risks from External Radiation Exposure

The risk coefficient used for low linear energy transfer - low dose rate occupational exposures is 3.9×10^{-4} (ECF)/rem (EPA 1994). This coefficient leads to an ECF risk of 3.9×10^{-3} for the maximum plausible risk and 9.8×10^{-4} for the average dose to the maximally exposed worker.

3.4 Comparison of VOC and External Radiation Risk

The risks from VOC releases and from external radiation exposure are shown in Table 3-5. Ratios of the radiation risk relative to the VOC risk are also given. There are several clarifying remarks about the table: (1) the assumptions for the various scenarios differ and may not contain equal degrees of conservatism; (2) the surface workers exposed to VOCs may not be occupationally exposed to radiation; and (3) the public resident at the site boundary is assumed to be exposed to low concentrations of VOCs from WIPP, but no radiation.

Table 3-5
Comparison of VOC and Radiation Cancer Risks^a

Exposed Person	Maximum Risk		Average Risk	
	Risk	Ratio Rad/VOC	Risk	Ratio Rad/VOC
Underground Worker, VOC	5.8×10^{-6}	670	5.6×10^{-8}	17,000
Surface Worker, VOC	1.0×10^{-5}	380	9.7×10^{-8}	10,000
Boundary Resident, VOC	1.0×10^{-6}	3900	9.4×10^{-9}	100,000
Radiation Worker	3.9×10^{-3}	–	9.8×10^{-4}	–

^a Values rounded from three significant figures.

3.4.1 Comparison of Risks to Workers

The results presented in Table 3-5 show that for the maximum postulated exposures radiation worker risks are approximately 400 to 700 times greater than VOC risks, or roughly two to three orders of magnitude. For more likely exposure scenarios, the average radiation risks are about four orders of magnitude greater than those from VOC exposure. The average VOC risk to workers is also less than the acceptable risk to members of the public.

These findings indicate that it is much more important, from a risk perspective, to control radiation exposures to workers than to control VOC exposures.

3.4.2 Risks to Resident at WIPP Site Boundary

Table 3-4 shows that average lifetime carcinogenic risks to the resident at the WIPP Site Boundary are over two orders of magnitude below the 1×10^{-6} target risk level set by NMED. Our calculations of the maximum risk confirm that the RBCLs set by NMED will achieve the target risk level.

4. RISKS FROM ACCIDENTS AND LONG-TERM RELEASES

Containers of TRU waste could be damaged and lose a portion of their contents during handling and emplacement at WIPP. Incidents could include dropped containers, punctures by fork lifts, fires, and roof falls in underground disposal rooms. The quantities of radioactive material released from these types of accidents have been evaluated in Environmental Impact Statements, SARs, and other WIPP reports by DOE and EEG over the years. Thus, there is some consensus about the approximate fraction of radionuclides that might be released from a waste container from an accident. The SAR estimates the frequency of seven different release scenarios to be 10^{-2} to $10^{-4}/y$ (each). This is equivalent to an estimate of 0.024 to 2.4 release accidents during the 35 y operating lifetime of the repository.

SAR evaluations of hazardous waste releases have been limited to VOCs. Typically it has been assumed that all VOCs in the headspace of a waste drum would be released in the event of a release from a drum. SEIS-II assumed that the fractional releases of hazardous metals was the same as for radionuclides. In the absence of specific data, this assumption is reasonable to use when comparing relative risks. Therefore, this report will assume that the fractional releases of hazardous metals are the same as for radionuclides.

4.1 Hazardous Metals Inventory

The average quantities per drum of the most abundant hazardous metals are taken from Table G-6 of SEIS-II and are shown in Table 4-1. No data have been reported on ranges of hazardous metals in waste containers. These values are considered more uncertain than the values for radionuclides and VOCs.

Table 4-1
Hazardous Metals-Average Quantities and Risks Per Waste Drum

Hazardous Metal	Kg per Drum	URF (m ³ /μg)	μg per ECF	ECF per drum
Lead	1.0	-	-	-
Beryllium	0.025	2.4×10 ⁻³	2.44×10 ⁸	0.10
Cadmium	4×10 ⁻⁴	1.8×10 ⁻³	3.27×10 ⁸	0.0012
Mercury	0.43	-	-	-

4.2 Operational Accidents

4.2.1 Relative Risks from Operational Accidents

Since the fractional releases of hazardous metals and TRU radionuclides are assumed to be the same for all operational accidents, the relative risk (i.e., the ratio of the radionuclide carcinogenic risk to the hazardous metals carcinogenic risk) can be calculated simply by determining the inhalation risk from all the contents of an average drum for hazardous metals and radionuclides.

Beryllium and cadmium are the only metals in Table 4-1 that are carcinogenic. The URF values and the ECFs per drum from inhalation are also shown in Table 4-1.

The ECFs per drum from TRU waste are determined from the rem/Ci value calculated in Table 4-2, the average Ci/drum (5.0), and the risk coefficient of 1×10⁻⁴ ECF/rem (NAS 1988).

The 2.0×10⁵ ECFs per drum of TRU waste is 2.0×10⁶ times the 0.10 ECFs per drum of hazardous metals.

Table 4-2
Rem/Curie Value for WIPP TRU Waste Inventory

Radionuclide	Curies at Closing	Fraction	Rem/Ci ^a	Fraction Rem/Ci
²³⁸ Pu	2.61×10 ⁶	0.641	3.92×10 ⁸	2.51×10 ⁸
²³⁹ Pu	7.95×10 ⁵	0.195	4.29×10 ⁸	0.84×10 ⁸
²⁴⁰ Pu	2.15×10 ⁵	0.053	4.29×10 ⁸	0.23×10 ⁸
²⁴¹ Am	4.48×10 ⁸	0.110	4.44×10 ⁸	0.49×10 ⁸
Total				4.07×10 ⁸

^a Values from EPA 1988

4.2.2 Absolute Risks from Operational Accidents

In the accident being evaluated, it was assumed that only one drum was breached in the WHB. The drum had an average radionuclide concentration and either the weighted average or RBCL VOC concentrations. This differs from the three WHB accidents in the SAR (crane failure, drum puncture, and drum drop) where four to seven drums were breached, and one drum had a high radionuclide concentration. However, the purpose of this report is to evaluate absolute and relative risks from likely rather than low probability accidents.

In an accident all of the VOCs in the drum headspace volume (an average of 146 ℓ) are assumed to be expelled. The URF, weighted average, and RBCL values from Table 3-1 and the molecular weight can be used to determine the headspace inventory and risk from each VOC. These values are shown in Appendix A (Table A-1). The risk from all the headspace VOCs is 1.2×10⁻⁵ for weighted average VOC concentrations and 1.3×10⁻³ for RBCLs.

It is necessary to calculate the absolute risks (in ECFs) to the maximally exposed worker from VOCs, radionuclides, and hazardous metals because their fractional releases are different. This absolute risk was calculated for a scenario where the instantaneous release from a drum is assumed to expand in an aerosolized cloud at the rate of ventilation air movement in the WHB.

The worker's intake can be modeled as an expanding hemisphere where the decreasing concentration in the cloud is integrated over the assumed time of exposure. The exact solution to this model is given in Appendix A.

The absolute risks from an operational accident are shown in Table 4-3. Three key assumptions were made: (1) the aerosolized and respirable release fraction of radionuclides and hazardous metals is 2.5×10^{-5} . This is an intermediate value among various scenarios modeled in the SAR; (2) the cloud expands in all directions at a rate of 25 centimeters per second; and (3) the maximally exposed worker is located 3 m from the point of release and is exposed to the cloud from 12 to 30 seconds after release.

The absolute risks and ratios for this scenario are shown in Table 4-3.

Table 4-3
Risks to Workers from Radionuclides and Hazardous Wastes
Released During Operational Accidents

Source	Risk	Rad/HW Risk
Radiation Released	1.5×10^{-4}	-
VOC Released (average)	3.7×10^{-10}	4.0×10^5
VOC Released (maximum)	3.8×10^{-8}	4.0×10^3
Hazardous Metals Released	7.5×10^{-11}	2.0×10^6

4.2.3 Risks to Public from Operational Accidents

Radionuclides and VOCs could escape the WHB if the HEPA filters were inoperative (unlikely) or from the underground if the effluent is not HEPA filtered (more likely). The relative risks would be the same assuming the same dispersion values for both radionuclides and VOCs and neglecting radionuclide deposition (about 10% at 800 m and 20% at 4 Km) before reaching the MIR. Absolute risks are low, about 9.5×10^{-9} at the WIPP Site Boundary for a 5 Ci drum.

4.3 Long-Term Releases to Surface

4.3.1 Relative Risks from Long-Term Releases

The CCA (DOE 1996b) provided the technical bases for EPA's determination that WIPP complied with the long-term performance standards in 40 CFR 191 Subpart B. The DOE concluded that the only significant long-term releases to the accessible environment were due to cuttings, cavings, spallings, and direct brine releases brought to the surface as a result of human intrusion into the repository when drilling for oil and gas. (see Figure 4-1). Direct brine releases accounted for less than 1% of the total radionuclide release at the 0.1 probability level and less than 30% at the 0.001 probability level.

Beryllium and cadmium both are quite insoluble. For example, the beryllium concentration in sea water (6×10^{-7} mg/l) is about 7×10^{-11} M. Cadmium's concentration in seawater (1.1×10^{-4} mg/l) is about 1×10^{-9} M. By comparison, the values used in the Performance Assessment Validation Test (an addendum to the CCA) for plutonium and americium ranged from 1.3×10^{-8} M to 8.8×10^{-6} M. This simple comparison suggests that both beryllium and cadmium are less soluble than plutonium and americium and that a direct brine release would not be enriched. Therefore, it is reasonable to assume that the fraction of radionuclide releases to hazardous metal releases for a human receptor on the surface would be the same as that existing in the waste at the time of intrusion. It is necessary to correct for decay in radionuclides before the human intrusion. If the intrusion is assumed to occur 1000 y after closure, the average concentration drops to 1.31 curies per drum and the radionuclide to hazardous metal risk is 5.2×10^5 .

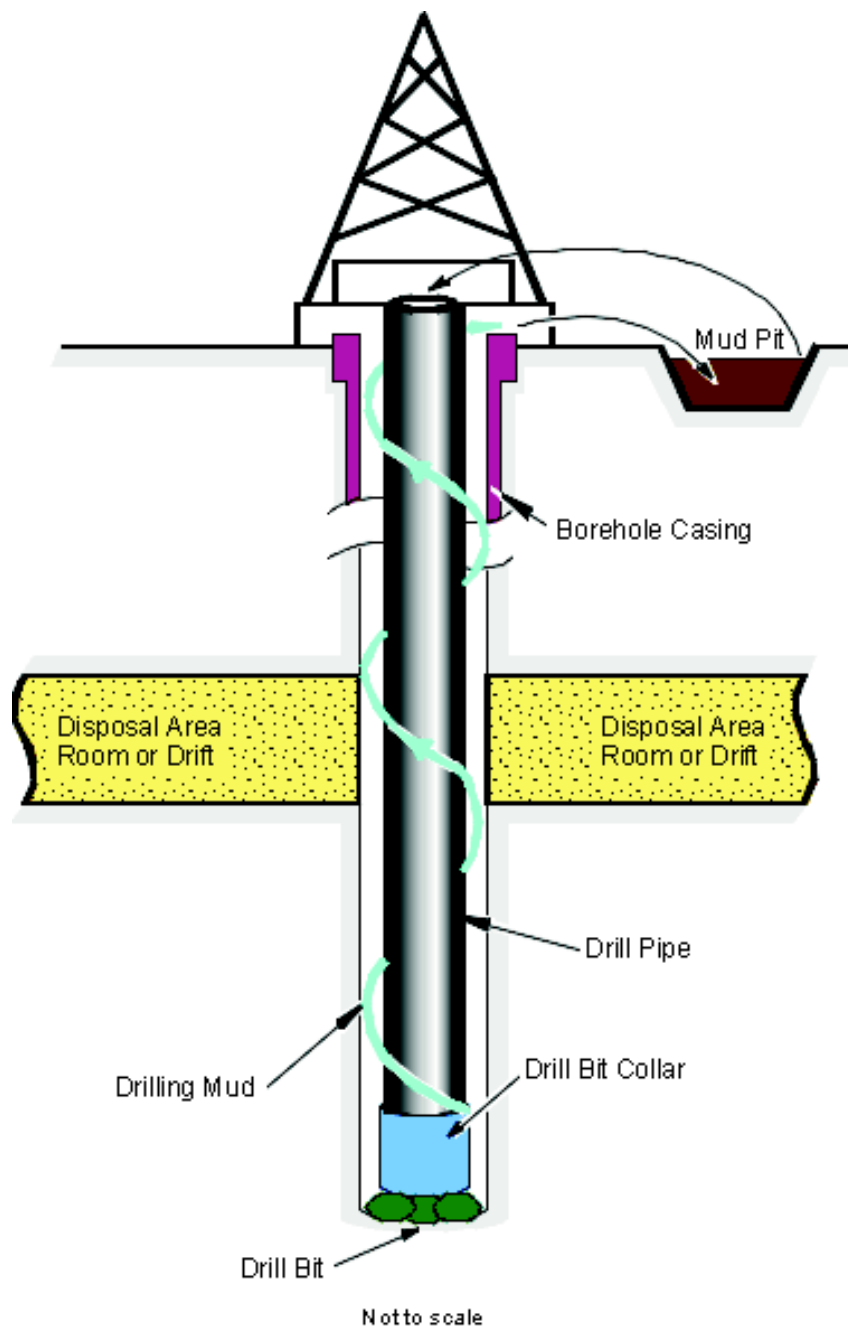


Figure 4-1. Schematic Representation of a Rotary Drilling Operation Penetrating the Repository (Source: DOE 1996b).

4.3.2 Absolute Risks from Long-Term Releases

The modeling assumptions used in the CCA resulted in no gaseous releases to the surface at the time of drilling in 92% of intrusions. The model did assume a significant release of gases from the entire repository 200 y after the intrusion when plugs in the intrusion borehole failed. A large fraction of the gases generated after this initial failure were also assumed to be released. The fraction of gases released from the repository varied significantly among vectors in the probabilistic calculations performed in the CCA. An average value of 85% was assumed in this report (Chapter 8 in Helton 1998).

The carcinogenic risk from releasing 85% of the VOCs in the repository was determined and compared to the risk from the radionuclides brought to the surface. The person receiving the exposure was assumed to be a resident farmer located 800 m from the borehole. Radionuclides and hazardous metals reached this person by resuspension from the drilling mud pit. The same assumptions were used as in EEG-66 (Channell 1998). VOC releases occur 200 y later and are dispersed in the atmosphere as they are vented. The same dispersion values (χ/Q) are used as in EEG-66. Risks to workers at the drilling rig were not used because a drilling rig is not expected to be located at this spot 200 y later.

The relevant assumptions used for VOC risk were: $\chi/Q = 5 \times 10^{-5} \text{ sm}^{-3}$, inhalation of 67 m^3 in 80 h of VOC releases, and total VOC releases equal to 1.02×10^6 drum headspace volume equivalents (85% of the VOCs in the repository, including equilibrium of room void space with drum headspace gas concentrations). Radionuclide overall release to surface quantity to ECFs value was determined from EEG-66 to be 7.1×10^{-7} ECF/Ci to surface. The mean volume of material brought to the surface was equivalent to 1.66 drums of waste, and the maximum volume was 8.29 drums.

Table 4-4 shows the relative risks of radionuclides and hazardous waste from material brought to the surface by human intrusion. The most likely radionuclide to VOC risk comparison is between

the average quantity and concentration of radionuclides and the average weighted concentration of VOCs. A comparison is also shown between an 8.3 drum, 17 Ci release (about a 5% probability of occurring in 10,000 y) and the room based concentration limits of VOCs.

Table 4-4
Risks of Radionuclides and Hazardous Waste
Brought to the Surface from Human Intrusion at 1,000 Years

Source	Expected Releases		Maximum Releases	
	Risk ^a	Ratio Rad/HW	Risk ^a	Ratio Rad/HW
Radionuclides	1.5×10^{-6}	–	1.2×10^{-5}	–
Hazardous Metals	3.0×10^{-12}	5.2×10^5	1.5×10^{-11}	8.1×10^5
VOCs	1.5×10^{-7}	1.0×10^1	1.5×10^{-5}	8.0×10^{-1}

^a Radionuclide and hazardous metal risks are for one year exposure. VOC risks are the total value.

Note that the radionuclide to VOC risk is only 10 for expected releases and is 0.80 for maximum releases. This high VOC risk occurs because the model assumes that 85% of the VOCs in the entire repository are released in this one-time occurrence. The radionuclide and hazardous metals release represents only 1.6×10^{-5} of the repository inventory. The ECFs for radionuclides and hazardous metals would continue for many years due to continuing resuspension from the drilling mud pit. So, the lifetime risk to a resident farmer from radionuclide releases would still be greater than the lifetime VOC risk to a (different) resident farmer even in the maximum case.

5. SUMMARY AND CONCLUSIONS

5.1 Summary

Table 5-1 summarizes the average radiological risk and the radiological to hazardous waste relative risks for normal operations, operational accidents, and long-term releases for CH-TRU wastes. Risks from maximum conditions are not summarized because they are considered less likely.

Table 5-1
Average Radiological to Hazardous Waste ECF^a Risks

Activity	Radiological Risk	Rad/VOC Risk	Rad/H. Metals Risk	Likelihood of Occ.
UG Worker	1×10^{-3}	2×10^4	–	~100%
Surface Worker	1×10^{-3}	1×10^4	–	~100%
Oper. Accidents	2×10^{-4}	4×10^5	2×10^6	2% to ~100%
Long-Term Rel.	2×10^{-6}	$1 \times 10^{1\ b}$	5×10^5	< 10% ^c

^a Excess Cancer Fatalities.

^b VOC risk is total; radionuclide and hazardous metal risks are for one year.

^c Likelihood of event approaches 100%, but the likelihood of a resident farmer at 800 m is < 10%.

It can be seen from Table 5-1 that the absolute risks to workers are higher for the more likely routine and operational accident activities. The radiological risks from these activities are four to six orders of magnitude greater than the VOC and hazardous metal releases.

The radiological to VOC risk for long-term releases is only one order of magnitude, and the exposed individual is a member of the public. There is also a risk to a member of the public at the WIPP Site Boundary from routine VOC releases, but none from routine radionuclide releases. The absolute risks in both cases are low, 9×10^{-9} lifetime risk at the WIPP Site Boundary and 2×10^{-7} from the long-term VOC release. This is three to five orders of magnitude less than the radiological risk to workers.

5.2 Discussion

5.2.1 Perspective on Risk

An implicit assumption that must be made in comparing these risks is that the exposure to excess cancer death risk coefficients used for the individual VOCs and for radiation exposure are of similar accuracy and uncertainty. However, there is considerable uncertainty in all of these values. All use the linear nonthreshold theory for cancer causation (i.e., that the probability of causing cancer is linearly related to the dose, and no dose is too small to potentially cause cancer), and it is not certain that this theory is valid for any or all of these carcinogens. However, the linear nonthreshold theory and the coefficients used are accepted by the appropriate regulatory agencies and will be accepted here without speculation about their accuracy and uncertainty.

The NMED is applying target risk levels at WIPP to be a maximum lifetime risk to a member of the public (the MIR) of less than 1×10^{-6} and a risk of less than 1×10^{-5} for a nonwaste surface worker. NMED is also requiring that the risks from individual VOCs be summed to determine a total risk. It is unclear whether RCRA requires the summation of risk (DOE contends it does not). The risks were summed in this report to provide an additional conservative measure. The risks to the MIR should be considered in the upper 95% confidence level (i.e., there is only a 5% chance of higher risks).

OSHA and DOE limits control occupational exposures to hazardous material and ionizing radiation rather than individual risks. However, risks are used in this report for comparison because the OSHA and DOE radiation limits are not equally conservative for lifetime carcinogenic risks. For example, the allowed radiation risk to a member of the public (25 mrem/y) during operation of WIPP (from 40 CFR Part 91, Subpart A) would amount to a lifetime risk of 3.4×10^{-4} for the 35 y emplacement period. This is 340 times the 1×10^{-6} lifetime target risk level allowed by NMED. Also, a surface nonradiation worker is permitted to receive a dose of 100 mem/y. For a 10 y exposure period, this would amount to a radiological risk of 3.9×10^{-4} or 39 times the allowed (1×10^{-5}) hazardous waste risk.

5.2.2 Probabilistic Considerations

This report used deterministic rather than probabilistic calculations for two reasons: (1) the primary objective was to obtain average absolute and relative risk values; and (2) no distribution data were available for hazardous metals. RBCL values for VOCs as well as for weighted average values were calculated because we believed these calculations provide an upper limit for possible VOC risk values. The RBCLs were set by NMED to ensure that target risk levels for nonwaste workers and the public were not exceeded and averaged about two orders of magnitude greater than the expected (weighted average values from 930 drums) values.

Routine releases and long-term releases are dominated by average conditions for a room, panel, or the entire repository rather than by the contents of individual waste containers. In operational accidents where releases involved one to seven drums, the risks for a single accident might vary significantly from the averages.

An examination of the data from the 930 drums that had been analyzed for headspace gas found that only six of these drums had headspace VOC concentrations that contained a higher risk per headspace volume than the RBCL values. The highest of these concentrations had a risk of 3.3×10^{-3} (2.57 times the RBCL risk). Use of the risk from this maximum drum would lower the relative radiological/VOC risk from 4.0×10^3 to 1.5×10^3 . This is not a significant change.

The radionuclide content of an untreated CH-TRU waste drum will vary from < 1 Ci to 80 Ci, and this will of course change both the absolute risk and relative risk ratio. The range of radiological to VOC risks for the operational accident could range from 10^2 to $> 10^7$. Thus, the radiological risk will always be much greater than the VOC risk, even for extreme cases of low radionuclide and high VOC concentrations.

5.3 Conclusions

Risks are low in all cases. Lifetime carcinogenic risks are expected to be about 1×10^{-3} for workers and about 1×10^{-8} for members of the public.

The findings of the evaluations in this report show that for both routine operations and accidents the expected carcinogenic risks to workers from the radiological component of the waste are at least four orders of magnitude greater than the HW component. Even under maximum conditions, the radiological risks are always at least two orders of magnitude greater. There is a low probability that the absolute risks of HW would approach the RCRA target levels allowed under conditions of the NMED Hazardous Waste Permit. However, these risk levels are 40 to 340 times less than the allowed radiation limits.

Hazard Index values from exposure of workers to non-carcinogens are less than 0.02 of allowable for RBCL concentrations and less than 0.01% for expected weighted average concentrations. Doses to radiation workers will be allowed to approach 20% (1 rem/y) of the allowable (5 rem/y), and some doses greater than 5% of the limit (250 mrem) are expected. Therefore, absolute exposures to non-carcinogenic VOCs are not a risk, and the expected exposures are a lower fraction of allowable limits than the expected radiation exposures.

A member of the public residing at the WIPP Site Boundary would receive a very low carcinogenic risk (less than 10^{-8} lifetime) from VOCs and no radiological risk from routine operations. Absolute risks to members of the public from average operational accidents are low, and the radiological risks are over five orders of magnitude greater than the VOC risks.

Risks from hazardous metal releases are one-fifth of the risks from VOC releases in operational accidents and over four orders of magnitude less for long-term releases.

Radionuclide risks from long-term releases to the surface are only an order of magnitude greater than VOC risks for expected conditions and are less than 1.0 in the maximum case. This relative risk comparison is less important than the others for several reasons: (1) the VOC risk is total and the radionuclide risk is only for one year; (2) the occurrence of this scenario is less likely than the others; (3) the model for VOC release, although taken from modeled gas behavior in the CCA, is uncertain, and other models could have been used; (4) the absolute risk is lower than those for the routine and operational accidents activities; and (5) the actual risks would probably be lower than shown in Table 5-1 because a member of the public is likely to be farther away and not in the prevailing wind direction.

These evaluations confirmed the intuitive assumption that radiological risks from WIPP wastes are much greater than the risks from hazardous wastes.

6. ACRONYMS & ABBREVIATIONS

ADF	Air Dispersion Factor
A&R	Aerosolized and Respirable
CCA	Compliance Certification Application
CH-TRU	Contact Handled Transuranic
Ci	Curie
DOE	U.S. Department of Energy
ECF	Excess Cancer Fatality
ECS	Exhaust Shaft Concentration
ECU	Exposure Concentration in the Underground
EEG	New Mexico Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
ft.	Feet
HEPA	High Energy Particulate Aerosol
HI	Hazard Index
HQ	Hazard Quotient
HW	Hazardous Waste
h	Hour
INEEL	Idaho National Engineering and Environmental Laboratory
IRIS	Integrated Risk Information System (EPA)
Km	Kilometers
LANL	Los Alamos National Laboratory
ℓ	Liter
MIR	Maximum Individual Receptor
m	Meters
μg	Micrograms
mg	Milligrams
min	Minute

ACRONYMS & ABBREVIATIONS

mrem	Millirem
mg/ℓ	Milligrams per liter
M	Molar
NAS	National Academy of Sciences
NMED	New Mexico Environment Department
OSHA	U.S. Occupational Safety and Health Administration
ppmv	Parts per million volume
RBCL	Room Based Concentration Limits
RCRA	U.S. Resource Conservation and Recovery Act
R _f C	Chronic reference dose for exposure to non carcinogens by inhalation
RH-TRU	Remote Handled Transuranic
SAR	WIPP Safety Analysis Report
SEIS-II	WIPP Disposal Phase Final Supplemental Environmental Impact Statement
TRU	Transuranic
TWA	Time Weighted Average for Exposure Concentrations
URF	Carcinogenic Unit Risk Factor
VOC	Volatile Organic Compound
WHB	Waste Handling Building
WIPP	Waste Isolation Pilot Plant
WMCG	Waste Matrix Code Group
y	Year

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APPENDIX A

APPENDIX A
**Calculation of Amount of Material Inhaled in an Operational
Accident Involving a Radioactive Release**

A common method of assessing the consequences to workers of a release accident involving CH-TRU drums is to assume that the aerosolized and respirable (A&R) material is released instantaneously and expands from a point source as a hemispherical cloud moving at the velocity of the ventilation flow rate. The maximum exposed worker is assumed to be at a given distance for a period of time before exiting the cloud.

The intake (and consequently the dose and the risk) can be solved exactly for this scenario as follows:

$$\text{Intake} = (\text{A\&R Concentration}) (\text{Duration of Exposure}) (\text{Inhalation Rate}) \quad (\text{A-1})$$

The A&R concentration varies with distance since the volume of the hemisphere is constantly increasing.

The A&R concentration is:

$$C_{A\&R} = \frac{\text{Amount Released} = Q}{\frac{2}{3}\pi r^3} \quad (\text{A-2})$$

The radius, r, of the hemisphere can be expressed as a function of time. If the assumed velocity is 25 centimeters per second, the expression becomes:

$$C_{A\&R} = \frac{Q}{\frac{2}{3}\pi(25t)^3} = \frac{3.05 \times 10^{-5} Q}{t^3} \quad (\text{A-3})$$

This function can be integrated with respect to time and when the inhalation rate (333cm³/s) is included can give the cumulative intake with an assumed time interval.

$$Intake = .0102 Q \int_{t_1}^{t_2} t^{-3} dt = -5.10 \times 10^{-3} Q t^{-2} \Big|_{t_1}^{t_2} \quad (\text{A-4})$$

$$I = 5.10 \times 10^{-3} Q \left[\frac{1}{t_1^2} - \frac{1}{t_2^2} \right]. \quad (\text{A-5})$$

This expression can be expanded to calculate the risk (excess cancer fatalities - ECF) by:

$$Risk = I \left(4.07 \times 10^8 \frac{rem}{Ci} \text{ inhaled} \right) \left(1 \times 10^{-4} \frac{ECF}{rem} \right) \left[\frac{Ci}{drum} \text{ (fraction released)} \right]. \quad (\text{A-6})$$

For a fraction released of 2.5×10^{-5} , the maximally exposed individual located at 3 m and an exposure time between 12 seconds (t_1) and 30 seconds (t_2), the risk becomes:

$$Risk = 5.19 \times 10^{-3} \left(\frac{Ci}{drum} \right) \left[\frac{1}{12^2} - \frac{1}{30^2} \right] = 3.02 \times 10^{-5} \left(\frac{Ci}{drum} \right). \quad (\text{A-7})$$

For an average drum containing 5.0 Ci, the risk is 1.51×10^{-4} ECF. The risk from hazardous metals is 5.05×10^{-7} of that from radionuclides or 7.63×10^{-11} .

VOC Risk

All VOCs in the drum headspace are assumed to be released in the accident. Table A-1 shows the risk if all the VOCs in the headspace were inhaled by the maximum exposed worker. The above expression can be adapted to determine the fraction of the total VOCs inhaled.

From Equation 5:

$$Intake = 5.10 \times 10^{-3} Q [5.83 \times 10^{-3}] = 2.97 \times 10^{-5} Q \quad (\mathbf{A-8})$$

Q can be taken as 1.0 drums and the risk per drum from Table A-1. Therefore, the risks for the weighted average concentration drum would be 3.71×10^{-10} ECF and for the RBCL drum would be 3.81×10^{-8} ECF.

Table A-1
Risks from VOCs in Drum Headspace Volume

VOC	mg per lifetime ^a for unit risk	Weighted Average Concentration		RBC Limits ^b	
		mg/drum	ECF per drum risk	mg/drum	ECF per drum risk
Methylene Chloride	1.25×10 ⁹	205.2	1.64×10 ⁻⁷	5.5× 10 ⁴	4.46×10 ⁻⁵
Chloroform	2.56×10 ⁷	19.8	7.73×10 ⁻⁷	7.15×10 ³	2.79×10 ⁻⁴
1,1,2,2-Tetrachloroethane	1.01×10 ⁷	10.4	1.03×10 ⁻⁶	3.00×10 ³	2.97×10 ⁻⁴
Carbon Tetrachloride	3.92×10 ⁷	378.9	9.67×10 ⁻⁶	1.16×10 ⁴	2.95×10 ⁻⁴
1, 1 Dichloroethylene	1.18×10 ⁷	7.31	6.22×10 ⁻⁷	3.21×10 ³	2.72×10 ⁻⁴
1, 2 Dichloroethane	2.26×10 ⁷	5.91	2.26×10 ⁻⁷	2.17×10 ³	9.62×10 ⁻⁵
Total			1.2×10 ⁻⁵		1.3×10 ⁻³

$$^a \frac{\text{mg}}{\text{lifetime}} = \frac{5.88 \times 10^5 \text{ m}^3 / \text{lifetime}}{\text{URF} \text{ m}^3 / \mu\text{g}} (10^{-3} \text{ mg} / \mu\text{g})$$

^b *RBCL Room Based Concentration Limit*