APPENDIX D9

EXPOSURE ASSESSMENT FOR PROTECTION OF THE ATMOSPHERE

D9-1 Introduction

The purpose of this analysis is for the assessment of potential human exposure to waste emissions in the atmosphere, and a comparison of that potential exposure to acceptable regulatory levels. 20 NMAC 4.1, Subpart V, §264.601 requires such an assessment for disposal of hazardous waste in a miscellaneous unit.

This assessment applies only to potential air emissions from waste containers during normal operations and the closure time period of the Waste Isolation Pilot Plan (WIPP) facility. In response to a request from the NMED, a calculation of releases during an offnormal event is also included. After final facility closure of the repository, no credible pathway will exist for air emissions. Once sealed, the waste is confined by engineered and natural barriers, which prevent the release of waste constituents in the atmosphere. In this assessment, only gaseous emissions will be considered as a source, because any particulate matter will be contained in the waste containers or panel closures and no liquid waste will be accepted for disposal. Of the gaseous constituents, the assessment is limited to volatile organic compounds (VOC), which comprise approximately 99 percent of the risk.

This appendix provides calculation details and summaries of risk assessments and worker exposures for the operational phase of the WIPP facility. The analyses included here are the

- risk to a hypothetical member of the public at the boundary of the site
- risk to potential members of the public within the boundary of the site
- assessments of worker exposure on the surface within the site
- assessments of worker exposure in the underground portion of the facility

The exhaust shaft concentration of VOCs, which are used in the exposure and risk assessments included in this appendix, are given in Section D9-2. The exposure scenarios are described in Section D9-3. The air dispersion modeling factors for the assessments are given in Section D9-4. Section D9-5 details the calculations for each risk and worker exposure assessment, and Section D9-6 summarizes the assessment results.

D9-2 Exhaust Shaft Concentrations of VOCs

During waste disposal at the WIPP facility, closure systems will be used to isolate waste in a filled panel and to eliminate ventilation through these filled panels. Similarly, as individual rooms within a panel are filled, ventilation barriers will be placed on the filled rooms to prevent the flow of ventilation air through these filled rooms and to isolate the rooms. Exhaust shaft concentrations of VOCs will thus vary with the number of filled, closed panels, the number of filled rooms with ventilation barriers within an open panel, and the number of drums in an open room.

D9-2.1 Exhaust Shaft Concentrations of VOCs from a Closed Panel

Exhaust shaft concentrations of VOCs from a single closed panel are calculated as follows:

$$SCPE = \frac{X \times GR \times HS \times \left(\frac{1\ mole\ fraction}{1 \times 10^6\ ppmv}\right) \times MW \times (1 \times 10^6\ \mu g/g) \times P_c}{V \times 0.0283\ m^3/ft^3 \times (525{,}600\ min/year)} \quad (D9\text{-}1)$$

where,

SCPE	=	exhaust shaft concentration of the VOC from a single closed panel, µg/m³
X	=	number of drums in a closed panel, 81,000 drums/panel
GR	=	effective gas generation rate, 0.5 moles/drum/year
HS	=	weighted average headspace concentration of the VOC, ppmv
MW	=	molecular weight of the VOC, g/mole
P_c	=	number of closed panel equivalents, 1 panel
V	=	mine ventilation exhaust rate, 425,000 ft³/min

Weighted average headspace concentrations are based on sampling and analysis of wastes from the Idaho National Engineering Laboratory (INEL) and the Rocky Flats Environmental Technology Site (RFETS). The weighted average headspace concentrations are derived in Appendix D13.

During the placement of waste at WIPP, closure systems will be used to isolate wastes in a full panel and to eliminate ventilation through these filled panels. Assuming a continuous fresh air flow across the filters, VOCs will diffuse from the drums at a rate that is dependent on the concentration gradient across the filters and the diffusion properties of the VOCs, as described in Appendix D12. After a panel is filled and the ventilation barrier is installed, which is the first step in the closure process, fresh air will no longer flow across the waste drums, and VOC concentrations in the dead air space above the filter will begin to buildup and approach the concentrations in the drum headspace. Therefore, the maximum concentration of VOCs that would be present in the panel atmosphere would be equivalent to the average drum headspace concentration. For the risk assessments, it is conservatively assumed that the average drum headspace concentrations serve as a constant source of VOCs.

The ventilation barrier design includes the use of low-permeability materials that restrict the diffusion of VOCs from the panel; therefore, gas pressurization is assumed to be the only process that would cause VOCs to migrate beyond a panel with a ventilation barrier installed (Appendix I1). Pressurization within a panel will be caused by gas generation and volume reduction due to creep closure of the repository. The panel closure systems will be designed to withstand some pressure buildup; however, for this evaluation, the leakage rate from the panel closure system is conservatively assumed to be equivalent to the effective gas generation rate.

Appendix D11 includes information on gas generation by WIPP waste. Of the gas-generating mechanisms described in Appendix D11, microbial degradation will contribute the most to the generation rate during the time periods of interest. The best estimate for gas generation from microbial degradation under humid conditions is 0.1 moles of gas per drum per year (see Appendix D11 and D16-5). The recommendation in D16-5 is for a rate of 0.02 moles/kg/year. This results in 0.2 moles/drum/year, based on 10kg of cellulosics per drum. However, the memo in D11 states that mocrobial degradation only occurs half of the time. This time results in a 0.1 mole/drum/year rate. For the period of time in this analysis, there is not expected to be enough brine flow into panels to create an inundated environment, which would be necessary to produce these and higher gas generation rates. This analysis conservatively assumes that a humid condition will exist to produce gas at a rate of 0.1 moles per drum per year.

Although Appendix D11 states that the maximum expected value for any one drum of waste is 0.4 moles per drum per year, the lowest expected value for any one drum is 0 moles per drum per year. A discussion of the relationship between gas generation, brine inflow, and creep closure can be found in Section I-1e(4). In reality, under the conditions that will initially exist in a closed panel, the predominant degradation mechanisms may consume gas at a rate faster than it is produced. This outcome is a function of the availability of nutrients to sustain microbial activities. Indications of gas consumption activities are in Francis and Gillow (1994), where they reported 200-day experiments (see Appendix D11).

The average creep closure rate, as discussed in Appendix I1, will result in a reduction of the panel void volume of 812 m^3 per year for each panel. Converting this volumetric reduction rate to a molar (gas) displacement rate, using the Ideal Gas Law:

$$GDR = \frac{812\ m^3}{panel/year} \times \frac{P}{RT} \qquad \text{(D9-2)}$$

Since one full panel contains 81,000 drums of waste, this rate expressed on a drum basis is:

$$GDR = \frac{812\ m^3}{panel/year} \times \frac{1\ atm}{\left(\frac{0.082\ L \cdot atm}{mole \cdot K}\right) \times (298K)} \times \left(\frac{1 \times 10^3\ L}{m^3}\right) \times (panel/81{,}000 drum)$$

$$GDR = 0.4\ mole/drum/year$$

$$GDR = (4.74\ x\ 10^3\ mole/panel/year) \times (panel/81{,}000drum)$$

An effective gas generation rate (gas generation rate plus gas displacement rate) can be calculated as follows:

$$GR = GGR + GDR \qquad \text{(D9-3)}$$

where,

GR = effective gas generation rate, mole/drum/year
GGR = gas generation rate due to microbial degradation in a humid environment, 0.1 mole/drum/year
GDR = gas displacement rate due to salt creep (creep closure), 0.4 mole/drum/year

$$GR = (0.1\ mole/drum/year) + (0.4\ mole/drum/year)$$

$$GR = 0.5\ mole/drum/year$$

D9-2.2 <u>Exhaust Shaft Concentrations of VOCs from an Open Panel without Ventilation Barriers</u>

Exhaust shaft concentrations of VOCs from an open panel without ventilation barriers on the filled rooms are calculated using the equation

$$SOPE = \frac{X \times ADE_{VOC} \times MW \times (1 \times 10^6\ \mu g/g) \times P_o}{V \times 0.0283\ m^3/ft^3 \times \left(\frac{1}{60\ s/min}\right)} \qquad \text{(D9-4)}$$

where,

$SOPE$ = exhaust shaft concentration of the VOC from a full open panel without ventilation barriers on the filled rooms, $\mu g/m^3$
X = number of drums in a full panel, 81,000 drums/panel
ADE_{VOC} = the average drum VOC emission rate, mole/s/drum
MW = molecular weight of the VOC, g/mole
P_o = number of open panel equivalents, 1 panel
V = mine ventilation exhaust rate, 425,000 ft^3/min

The average drum emission rate for each VOC is calculated from the diffusion rate using the following equation:

$$ADE_{VOC} = D_{VOC} \times MF_{VOC} \times 31{,}536{,}000\ s/year \qquad \text{(D9-5)}$$

where,

ADE_{VOC}	=	average drum VOC emission rate, mole/drum/year
D_{VOC}	=	the VOC diffusion characteristic through a model NFT-013 carbon composite filter, mole/s/mole fraction/drum
MF_{VOC}	=	mole fraction of the VOC, mole/mole

The mole fraction of each VOC is calculated from its weighted average headspace concentration by:

$$MF_{VOC} = (HS_{VOC}) \times (10^{-6}\ mole\ fraction/ppmv) \qquad \text{(D9-6)}$$

where,

MF_{VOC}	=	mole fraction of the VOC, mole/mole
HS_{VOC}	=	average headspace concentration for VOC, ppmv.

For filter-specific diffusion characteristics, the ratio of VOC-to-H_2 diffusivities in air are calculated as follows:

$$\frac{D_{VOC-air}}{D_{H_2-air}} = \left(\frac{P_{c,VOC}}{P_{c,H_2}}\right)^{1/3} \times \left(\frac{T_{c,VOC}}{T_{c,H_2}}\right)^{-1/2} \times \left[\frac{\left(\frac{1}{MW_{air}} + \frac{1}{MW_{VOC}}\right)}{\left(\frac{1}{MW_{air}} + \frac{1}{MW_{H_2}}\right)}\right]^{1/2} \qquad \text{(D9-7)}$$

where,

$D_{VOC\text{-}air}$	=	diffusivity of the VOC in air, mole/s/mole fraction/drum
$D_{H2\text{-}air}$	=	diffusivity of hydrogen in air, mole/s/mole fraction/drum
$P_{c,\,VOC}$	=	critical pressure of the VOC, atm
$P_{c,H2}$	=	critical pressure of hydrogen, 12.8 atm
$T_{c,VOC}$	=	critical temperature of the VOC, K
$T_{c,air}$	=	critical temperature of hydrogen, 33.2K
MW_{VOC}	=	molecular weight of the VOC, g/mole
MW_{H2}	=	molecular weight of hydrogen, 2.016 g/mole
MW_{air}	=	molecular weight of air, 28.946 g/mole

The filter-specific VOC diffusion characteristics from the ratio of VOC-to-H_2 diffusivities in air are calculated using the following equation:

$$D_{VOC} = \left(\frac{D_{VOC\text{ - }air}}{D_{H_2\text{- }air}} \right) \times D_{H_2} \qquad \text{(D9-8)}$$

where,

D_{VOC} = the VOC diffusion characteristic through a model NFT-013 carbon composite filter, mole/s/mole fraction/drum

D_{H2} = the diffusion characteristic for hydrogen through a model NFT-013 carbon composite filter, 1.17E-5 mole/s/mole fraction/drum.

VOC-specific properties for calculating diffusion rates, the SOPE, and the SCPE are given in Table D9-1.

VOCs considered in all calculations are indicator VOCs selected using the screening technique in EPA (1989, p 5-23). These indicator VOCs represent approximately 99 percent of the risk due to air emissions. This screening methodology is described in detail in Appendix D13.

TABLE D9-1

PROPERTIES USED IN CALCULATING DIFFUSION RATES AND EMISSION CONCENTRATIONS

Constituent	*Pc* Critical Pressure (atm)	*Tc* Critical Temperature (K)	*MW* Molecular Weight (g/mole)	*Dvoc* Diffusivity (mole/s/mole fraction/ drum)	*HS* Weighted Average Concentration (ppmv)
Carbon Tetrachloride	45	556.4	153.84	1.21E-06	375.5
Chlorobenzene	44.6	632.4	112.56	1.16E-06	12.5
Chloroform	54	536.4	119.39	1.34E-06	25.3
1,1-Dichloroethylene	51.3	495	96.95	1.40E-06	11.5
1,2-Dichloroethane	53	561.6	98.97	1.32E-06	9.1
Methylene Chloride	60	510	84.94	1.47E-06	368.5
1,1,2,2-Tetrachloroethane	57.6	644.5	167.86	1.21E-06	9.4
Toluene	40.6	591.7	92.13	1.19E-06	19.4
1,1,1-Trichloroethane	42.4	545	133.42	1.21E-06	317.1

ppmv = parts per million by volume

D9-2.3 Public Exposure Concentrations of VOCs

As the waste disposal operations proceed, an increasing number of drums are emplaced in the open panel contributing to the exhaust shaft concentration. In addition, an increasing number of closed panels contribute to the exhaust shaft concentration over time.

The exhaust shaft concentrations for 9 closed and one open panel are conservative for any exposure prior to filling the last panel. From the full open panel, maximum VOC emissions will depend on the presence of ventilation barriers outside the filled rooms. Two levels of conservatism are possible: (1) assuming that rooms in the full panel do not have ventilation barriers installed and VOC emissions are from all drums (i.e., 81,000) in the panel and (2) assuming that the filled rooms within the open panel have ventilation barriers installed and only the drums (i.e., 11,571) in the last room are freely contributing to VOC emissions. The average exhaust shaft VOC concentration over the operational period of the facility will be lower than the maximum for 9 closed panels and 1 full open panel.

The maximum exhaust shaft concentrations of VOCs from 9 closed panels and one open panel without ventilation barriers outside the filled rooms is calculated as EC_{max} using the equation

$$EC_{max} = (P_c \times SCPE) + (P_o \times SOPE) \qquad \text{(D9-9)}$$

where,

EC_{max} = exhaust shaft concentration of the VOC from 9 closed panels and 1 full open panel without ventilation barriers outside the filled rooms, µg/m³

P_c = number of closed panel equivalents, 9 panels

P_o = number of open panel equivalents, 1 panel

D9-2.4 Surface Worker Exposure Concentration

The maximum exposure concentration for the worker on the surface of the facility is based on emissions from 9 closed and 1 full open panel with ventilation barriers on 6 of the seven rooms. The surface worker exposure concentration is calculated from the exhaust shaft concentration multiplied by the ADF. The exhaust shaft concentration is calculated:

$$ECS_{MAX} = \frac{(AOPE_{VOC}) + (P_C \times R_C \times ACRE) \times MW \times 1 \times 10^6 \ \mu g/g}{Q \times 0.0283 \ m^3/f^3 \times 525{,}600 \ min/yr} \qquad \text{(D9-11)}$$

where,

ECS_{MAX} = exhaust shaft concentration of the VOC from 9 closed panels and 1 full open panel with ventilation barriers, µg/m³

$AOPE_{VOC}$ = average open panel VOC emission rate, mole/panel/year

P_c = number of closed panel equivalents, 9 panels
R_c = number of closed rooms in the open panel, 7 rooms/panel
$ACRE_{VOC}$ = average closed room VOC emission rate, mole/room/year
MW = molecular weight of the VOC, g/mole
Q = ventilation rate through the mine, 425,000 ft^3 /minute

The average open panel yearly emission rate (AOPE) for each VOC is based on the number of full rooms, the number of drums in the open room, and the emission rates from each type of room. AOPE for 1 open and 6 closed rooms is calculated as:

$$AOPE_{VOC} = (R_o \times AORE_{VOC}) + (R_c \times ACRE_{VOC}) \qquad \text{(D9-12)}$$

where,

$AOPE_{VOC}$ = average open panel VOC emission rate, mole/panel/year
$AORE_{VOC}$ = average open room VOC emission rate, mole/room/year
$ACRE_{VOC}$ = average closed room VOC emission rate, mole/room/year
R_o = number of open rooms in the open panel, 1 room/panel
R_c = number of closed rooms in the open panel, 6 room/panel

The open room emission rate (AORE) is dependent on the number of drums that have been emplaced in the room and the diffusion of VOCs across the drum vent filters. Assuming a continuous fresh air flow across the filters, VOCs will diffuse from the drums at a rate that is dependent on the concentration gradient across the filters and the diffusion properties of the VOCs, as described in Appendix D12. The AORE is calculated using the equation

$$AORE_{VOC} = ADE_{VOC} \times D \qquad \text{(D9-13)}$$

where,

$AORE_{VOC}$ = average open room VOC emission rate, mole/room/year
ADE_{VOC} = average drum VOC emission rate, mole/drum/year
D = number of drums in the room, drum/room.

The average yearly closed room emission rate (ACRE) for each VOC is calculated as:

$$ACRE_{VOC} = (GR) \times (11{,}571\ drum/room) \times MF_{VOC} \qquad \text{(D9-14)}$$

where,

$ACRE_{VOC}$ = average yearly closed room VOC emission rate, mole/room/year
GR = effective gas generation rate, mole/drum/year
MF_{VOC} = VOC mole fraction, mole/mole

GR is defined as above for gas generation through closed panels. Similar to panel closures, ventilation barriers will be used to isolate wastes in a full room and to eliminate ventilation through these filled rooms. As for panels (Section D9-2.1), gas pressurization is assumed to be the only process that would cause VOCs to migrate beyond a closed room. The effective gas generation rate used for calculating ACRE, then, is 0.5 moles/drum/year.

D9-2.5 Underground Worker Exposure Concentration

The maximum exposure concentrations of VOCs to workers is the hazardous waste worker who is emplacing waste at the beginning of the next open room, which will place the worker downstream in the ventilation air of previously filled rooms with ventilation barriers, but always upstream of the open room waste. This concentration is calculated as folows:

$$ECU_{max} = \frac{(R_C \times ACRE_{VOC}) \times MW \times 10^6\ \mu g/g \times P_o}{Q \times 0.0283\ m^3/ft^3 \times 525{,}600\ min/year} \qquad \text{(D9-10)}$$

where,

ECU_{max}	=	exposure concentration of the VOC from 1 full open panel with ventilation barriers on the filled rooms, $\mu g/m^3$
R_c	=	number of closed rooms in the open panel, 6 room/panel
$ACRE_{VOC}$	=	average closed room VOC emission rate, mole/room/year
MW	=	molecular weight of the VOC, g/mole
P_o	=	number of open panel equivalents, 1 panel
Q	=	ventilation rate through the open room, 35,000 ft^3 /minute

D9-3 Exposure Assessment

In order to assess the potential public exposure to hazardous constituents in the air, first the probable public activities both outside and inside the WIPP site boundary during the 35-year operational/closure time frame are evaluated. Exposure scenarios for potential receptors both outside and inside the WIPP site boundary are then described.

D9-3.1 Public Activity Outside the WIPP Site Boundary

The most prevalent public activity currently outside the WIPP site boundary is oil and gas production. Several wells are located along the boundary, and drilling activities may require oil workers to be present continuously, but not for several years at a time. Oil activities could be ongoing 24 hours-a-day, 7 days-a-week, up to six months at a time, but the same oil workers are not likely to be present for several years.

Since the land immediately adjacent to the WIPP site boundary is federal or state land, a family could not theoretically build a house or dwelling at the boundary; however, one could potentially occupy that space for long periods of time. Currently, there are only 27 residents within a 10-mile radius of the WIPP facility, and the closest dwelling is the Mills ranch house approximately 3/4 miles south of the southwest corner of the WIPP site boundary (Figure D9-1).

D9-3.2 Public Activity Inside the WIPP Site Boundary

As shown in Figure D9-1, the area of land that lies within the WIPP site boundary contains approximately 10,240 acres including Sections 15-22 and 27-34 in Township 22 South and Range 31 East. This area contains three other distinct boundaries that limit public access. The innermost boundary, which contains most of the WIPP facility structures, is surrounded by a chain link fence and covers approximately 35 acres in Sections 20 and 21. This fenced area is known as the Property Protection Area. Only persons on official business are allowed within this area. Access is controlled by a 24-hour per day security force. The next area is surrounded by a barbed-wire fence, covers approximately 424 acres, and is posted "No Trespassing." This area is known as the Exclusive Use Area. The public may access this area for short periods of time for limited purposes. This area is patrolled frequently by the security force. The third area covers approximately 1,450 acres, is posted "No Trespassing," and is known as the Off Limits Area. Within this area, certain activities, such as hunting, are prohibited. Other forms of public access are allowed with permission of the DOE. The fourth area covers approximately 10,240 acres and is leased for cattle grazing.

Public access is allowed inside the WIPP site boundary for various activities and for various periods of time. Activities that take place inside the WIPP site boundary are described in detail in DOE (1993).

D9-3.2.1 Agricultural Uses

All the land within the WIPP site boundary outside the Exclusive Use Area has been leased for grazing, which is the only significant agricultural activity in the vicinity. There are two leaseholders as shown in Figure D9-1. The Livingston Ridge Allotment, currently leased by Kenneth Smith, Inc., of Carlsbad, New Mexico, includes 2,880 acres within the northern portion of the WIPP Site. J.C. Mills of Abernathy, Texas, current lessee of the Antelope Ridge Allotment, has lease rights to 7,360 acres within the southern portion of the WIPP Site.

D9-3.2.3 Recreational Activities

Hunting, camping, horseback riding, hiking, wildlife watching, and sightseeing are all activities that may be permitted inside the WIPP site boundary up to the boundaries marked "No Trespassing". Campers are required to check in with WIPP Security personnel before establishing camp. Although all of these activities are allowed and managed (DOE 1993), no member of the public is expected to perform any of these activities on WIPP property for long periods of time. Hunting durations are short and are established and enforced by the State of New Mexico. The other activities mentioned above are not likely to occur, because the WIPP facility is in a hot, arid environment, and much more scenic areas are in the vicinity for these activities (e.g., Guadalupe Mountains).

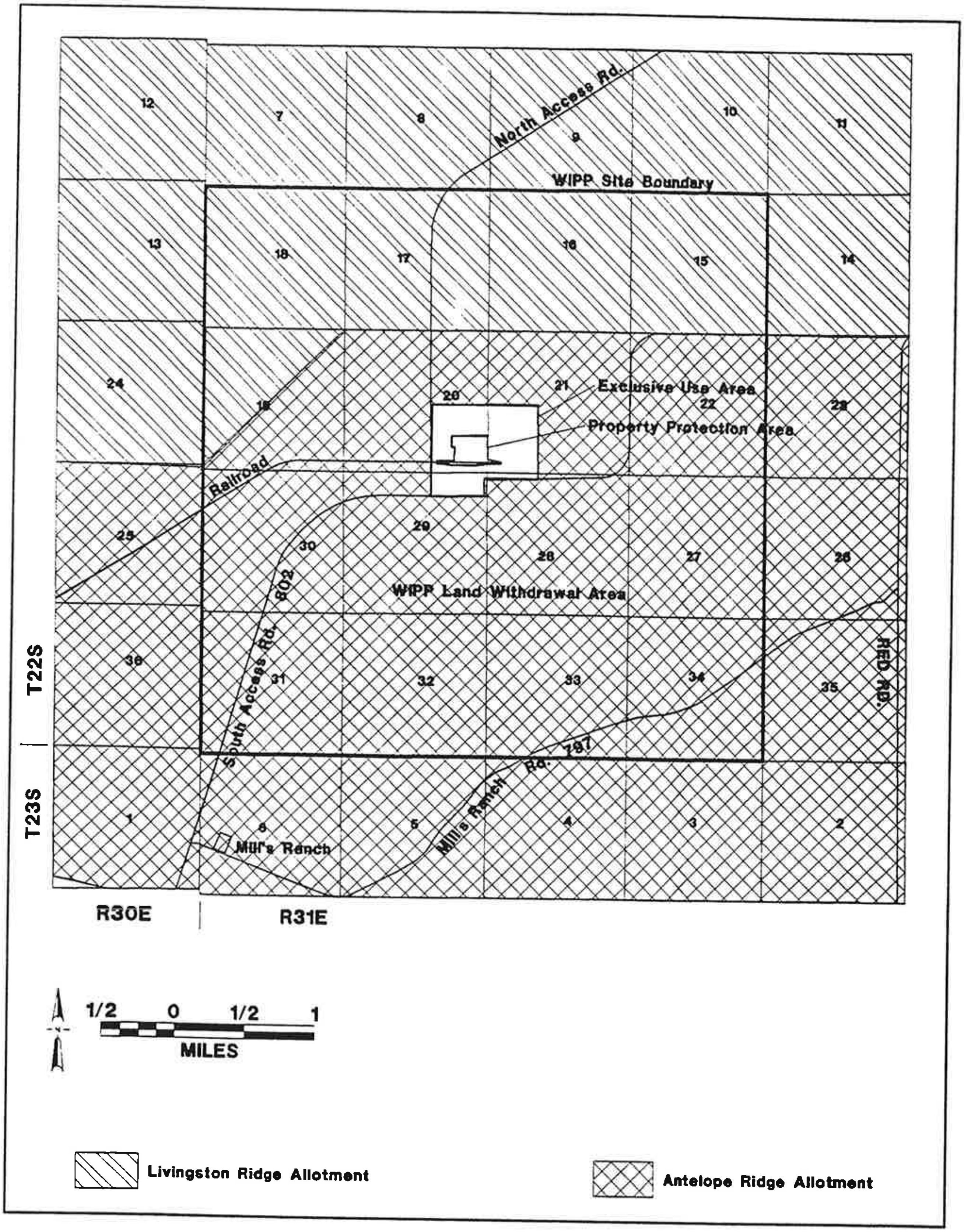

Figure D9-1
Grazing Allotments in the Vicinity of the WIPP Land Withdrawal Area

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D9-3.2.4 Scientific Research

Some scientific research is conduced for WIPP-related activities (i.e., archaeological and geological studies), but public research inside the WIPP site boundary does not typically occur. If such studies were to occur in the future, the time frame for such studies would be short-term (hours, days, or weeks at most) and would not pose significant exposure concerns for the public.

D9-3.3 Public Exposure Outside the WIPP Site Boundary

The worst-case exposure just outside the WIPP site boundary is conservatively assumed to occur to the hypothetical member of the public who could occupy space on the boundary up to 24 hours-a-day, 365 days-a-year, for 35 years (EF = 8760 hours/year, ED = 35 years, AT = 613,200 hours). This exposure scenario is referred to in following sections as the ***Boundary Public Receptor***. The Boundary Public Receptor exposure scenario is not considered a realistic scenario because residents around the facility live some distance away from the site boundary. More realistic exposure scenarios are those relating to ranching activities within the site boundary as discussed below.

D9-3.4 Public Exposure Inside the WIPP Site Boundary

The worst-case exposure of a member of the public to hazardous constituents released into the air around the WIPP facility is assumed to occur to the rancher who may be on land leased for cattle grazing. The exposure is assumed to be equally likely for any point within the area. The assumption is conservative, because the ranch hand is typically inspecting fences and watering facilities, which takes him to isolated locations either on the periphery of the grazing area or to locations which are not principle downwind locations. DOE is responsible for inspecting the fence on the boundary of the grazing allotment adjacent to WIPP. Because no actual statistics exist regarding the amount of time a ranch hand may spend at any field location on a ranch, the DOE had to make several assumptions in order to prepare the exposure analysis. The exposure time assumptions have been made in a manner that tends to overestimate exposures. First, it is assumed that a ranch hand spends 8 hours per day, 5 days per week (EF = 2080 hours/year) for 35 years (ED = 35 years, AT = 613,200 hours)working the ranch. This is conservative, because ranchers rotate pastures to protect them from overgrazing. As a result, there will be extended periods of time when there will be no activity in the grazing areas within the WIPP site boundary. Second, it is assumed that a single ranch hand from each ranch works only on the portions of the leases within the WIPP site boundary. This is conservative, because the lease covers a much larger area than what lies within the WIPP site boundary. Third, the exposure assessment is based on the average ground-level, rather than inhalation level, concentrations of hazardous constituents for each area of grazing-leased land between the WIPP site boundary and the Exclusive Use Area.

For the exposure assessment, two hypothetical receptors are evaluated, corresponding to ranchers working on each of the two grazing allotments within the WIPP site boundary. The exposure scenarios are referred to in following sections as ***Livingston Ridge Rancher*** and ***Antelope Ridge Rancher***.

D9-3.5 Occupational Exposure Inside the WIPP Site Boundary

Two additional exposure scenarios that hypothetically occur within the WIPP site boundary are also evaluated in this appendix. One additional scenario is that of a worker who works on site 1,920 hours/year (EF = 1,920 hours/year), for 10 years (ED = 10 years, AT = 613,200 hours) on the surface near the exhaust shaft. The 1920 hours are the hours for an employee after removing vacations and holidays. This is conservative since workers spend approximately ten percent of their time off site at training, travel, and meetings. The ten year exposure duration represents normal turnover in employees. Turnover, in this case includes new employment, new positions and new locations at the facility. The exposure location chosen corresponds to the maximum VOC exposure at the surface within the site boundary and is located in the property protection area. The scenario is referred to in following sections as ***Surface Worker***.

The second scenario is that of an underground worker who works "downwind" of a full, but closed room. This worker performs hazardous waste duties and is estimated to be working downstream of a closed room while beginning to fill each subsequent room 33 hours/year for 10 years. The underground worker exposure scenario is a worst-case exposure scenario, and is referred to in the following sections as ***Underground Worker***. The exposure frequency was developed based on the expected operational throughput times in Figure D-36 and the number of waste locations in the area of a room (130) that is downwind from a room exhaust. The 130 positions represents stacks that are 3 high, so 390 waste units (7-pack, SWB, 4-pack, or TDOP) are involved. These configurations represent approximately 100 pallets of waste, which take 30 minutes per pallet to emplace or 50 hours per room. Backfill requires 30 minutes every time a row of 5 stacks is complete. Since there are 26 rows in this area (130 ÷ 5), 13 hours for emplacing backfill is needed. This results in a total of 63 hours per room that are spent downwind from full rooms. Finally, a waste worker will be downwind for Rooms 6 through 1; however, the amount of waste in the Room 1 entry is 32 positions (1/4 of Rooms 2-6) so that the total exposure time in a panel is 63 × 5.25 = 330 hours. This exposure occurs over the 2.5 years required to fill the panel and is shared equally by four waste workers resulting in an annual exposure of 330 ÷ 2.5 ÷ 4 = 33 hours/year.

D9-4 Air Dispersion Modeling

This section presents the results of specific air dispersion modeling performed inside and outside the WIPP site boundary that are used in assessing the scenarios described in Section D9-3 for exposures at the surface, that is, for the Boundary Public, Livingston Ridge Rancher, Antelope Ridge Rancher, and Surface Worker. The Long-Term Version of the Industrial Source Complex (ISCLT3) model, EPA (1995), was used for the air dispersion modeling. Concentrations were modeled in accordance with EPA (1992). Details of the modeling is described in Appendix D10.

To determine areas where the maximum concentrations may occur, the air dispersion model was run with a coarse receptor grid of 400 meters (see Figure D9-2). To model the boundary public exposures, the air dispersion model was run with a fine receptor grid of 10 meters around the point of highest concentration predicted on the boundary during the coarse grid

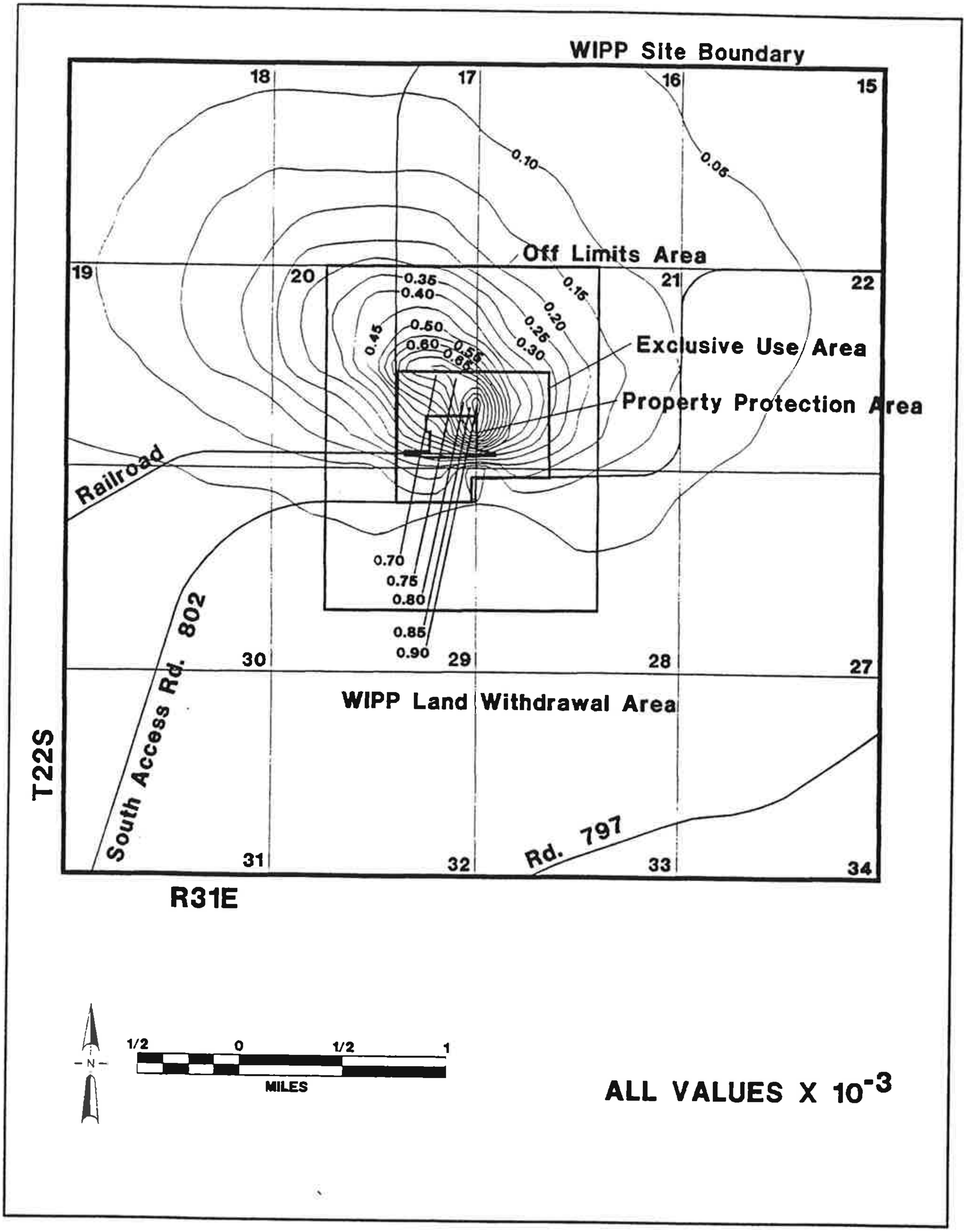

Figure D9-2
Air Dispersion Factors at WIPP

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run. To determine the exposure concentrations at the WIPP site boundary, the annual average concentration anywhere on the boundary is used to determine the ADF for the boundary public receptor. That average concentration, which was modeled from an arbitrary 1,000 $\mu g/m^3$ source, is divided by 1,000 $\mu g/m^3$ to arrive at the air dispersion factor (ADF) used in the risk calculations presented in Section D9-5. The ADF for the boundary public receptor is 1.2×10^{-4} (Table D9-2).

For the rancher exposure assessments, the coarse grid run mentioned above was used. This grid covers all of the leased land within the WIPP site boundary as shown in Figure D9-1. All concentrations derived in the model run were then averaged for each lease, representing an average exposure concentration throughout the leased land inside the boundary. The resulting ADF for the Livingston Ridge Allotment is 9.8×10^{-5} and the ADF for the Antelope Ridge Allotment is 6.7×10^{-5}.

For determining the exposure concentrations to the surface worker, the model was run with a fine receptor grid of 10 meters around the area with the highest concentration inside the WIPP site boundary predicted during the coarse grid run (see Figure D9-3). This area was near the exhaust fans. The ADF for the surface worker is 1.23×10^{-2}.

TABLE D9-2
AIR DISPERSION FACTORS FOR WIPP SITE AREAS

Area	Averaged/Modeled Concentration ($\mu g/m^3$)	Air Dispersion Factor (ADF)
WIPP Site Boundary	1.2E-01	1.2E-04
Livingston Ridge Allotment	9.8E-02	9.8E-05
Antelope Ridge Allotment	6.7E-02	6.7E-05
WIPP Property Protection Area	1.23E+01	1.23E-02

D9-5 Receptor Concentrations and Risk Calculations

Risks and hazards for the public exposure scenarios described in Section D9-3 are described in this section. Also presented are evaluations of VOC concentration levels to worker receptors. The equations used in assessing excess risk from carcinogens and hazard from noncarcinogens are derived and given. The calculations use exposure factors as appropriate for the exposure scenarios. ADFs are used for the Boundary Public, Livingston Ridge Rancher, Antelope Ridge Rancher, and Surface Worker scenarios. The calculations assume the receptors are subjected to concentrations based on maximum exhaust shaft VOC concentrations, which are those concentrations that result from emissions from 9 closed and

1 full open panels. The full open panel is conservatively assumed to contain no room closures for assessing impacts to the public at the surface, that is, the Boundary Public, Livingston Ridge Rancher, Antelope Ridge Rancher, and Surface Worker scenarios. These scenarios also include model estimates of concentrations from air dispersion. For assessing impact to an underground worker, only one full open panel is used and is assumed to contain room closures. Since this worker is exposed to underground concentrations, no air dispersion takes place before exposure.

D9-5.1 Public Risk Outside the WIPP Site Boundary

The Boundary Public exposure scenario is evaluated in this section. An ADF of 1.2×10^{-4} is used in assessing risk from emissions from 9 closed and 1 open panel equivalents, with no credit taken for room closures within the open panel.

D9-5.1.1 Carcinogens

For carcinogens, risk is calculated as follows:

$$Risk = \frac{EC \times ADF \times URF \times EF \times ED}{AT} \qquad \text{(D9-15)}$$

where,

- $Risk$ = a unitless probability (e.g., 2×10^{-5}) of an individual developing cancer
- EC = maximum exhaust shaft concentration for the VOC, µg/m³, EC_{max}
- ADF = air dispersion factor, unitless, 1.2×10^{-4}
- URF = unit risk factor for VOC, $(\mu g/m^3)^{-1}$
- EF = exposure frequency, 8,760 hours/year (24 hours/day × 365 days/year)
- ED = exposure duration, 35 years
- AT = averaging time, 613,200 hours (24 hours/day × 365 days/year × 70 years)

Equation D9-15 was derived from equations in EPA (1989); the derivation is shown below.

EPA (1989), page 6-44, provides the calculation of residential exposure from inhalation of airborne (vapor phase) chemicals as:

$$Intake = \frac{CA \times IR \times EF \times ED}{BW \times AT} \times \left(\frac{mg}{1 \times 10^3\ \mu g}\right) \qquad \text{(D9-16)}$$

where,

- $Intake$ = receptor intake, mg/kg-day
- CA = contaminant concentration in air, µg/m³
- IR = inhalation rate, 20 m³/day

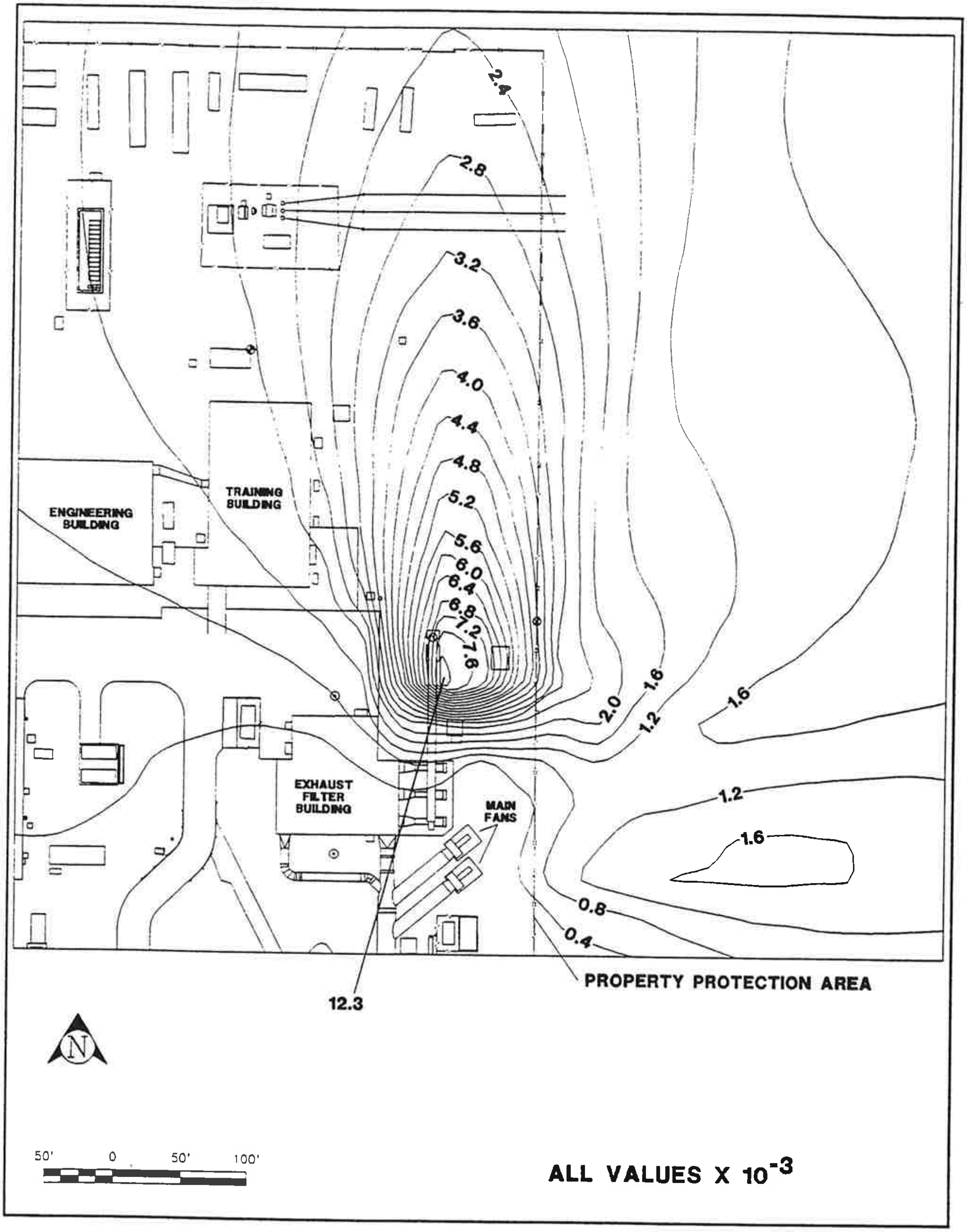

Figure D9-3
Air Dispersion Factors Inside the Property Protection Area

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EF = exposure frequency, hours/year
ED = exposure duration, years
BW = body weight, 70 kg
AT = averaging time, days

EPA (1989), page 8-6, also describes chronic intake as:

$$Intake = \frac{Risk}{SF} \qquad (D9\text{-}17)$$

where,
$Intake$ = receptor intake, mg/kg-day
$Risk$ = a unitless probability (e.g., 2×10^{-5}) of an individual developing cancer
SF = cancer slope factor, $(mg/kg\text{-}day)^{-1}$

To express the carcinogenic effect in terms of unit risk factor, as provided in EPA (1989), page 7-13, the following equation is used:

$$URF = \frac{SF \times IR}{BW} \times \left(\frac{mg}{1 \times 10^3\ \mu g}\right) \qquad (D9\text{-}18)$$

where,
URF = unit risk factor, unitless
IR = inhalation rate, 20 m^3/day
BW = body weight, 70 kg
SF = cancer slope factor, $(mg/kg\text{-}day)^{-1}$

Solving for slope factor in equation D9-18:

$$SF = \frac{URF \times BW}{IR} \times \left(\frac{1 \times 10^3\ \mu g}{mg}\right) \qquad (D9\text{-}19)$$

where,
SF = cancer slope factor, $(mg/kg\text{-}day)^{-1}$
URF = unit risk factor, unitless
BW = body weight, 70 kg
IR = inhalation rate, 20 m^3/day

Combining equation D9-17 and D9-19:

$$Intake = \frac{Risk \times IR}{URF \times BW} \times \left(\frac{mg}{1 \times 10^3\ \mu g}\right) \qquad \text{(D9-20)}$$

where,

Intake	=	receptor intake, mg/kg-day
Risk	=	a unitless probability (e.g., 2×10^{-5}) of an individual developing cancer
IR	=	inhalation rate, 20 m^3/day
URF	=	unit risk factor, unitless
BW	=	body weight, 70 kg

Setting equations D9-16 and D9-20 equal to each other:

$$\frac{Risk \times IR}{URF \times BW} \times \left(\frac{mg}{1 \times 10^3\ \mu g}\right) = \frac{CA \times IR \times EF \times ED}{BW \times AT} \times \left(\frac{mg}{1 \times 10^3\ \mu g}\right)$$

and solving for risk yields equation D9-21:

$$Risk = \frac{CA \times URF \times EF \times ED}{AT} \qquad \text{(D9-21)}$$

where,

Risk	=	a unitless probability (e.g., 2×10^{-5}) of an individual developing cancer
CA	=	contaminant concentration in air, $\mu g/m^3$
URF	=	unit risk factor, unitless
EF	=	exposure frequency, hours/year
ED	=	exposure duration, years
AT	=	averaging time, days

For this assessment, the contaminant concentration in air is the exhaust shaft concentration in air (EC) multiplied by the ADF as follows:

$$CA = EC \times ADF \qquad \text{(D9-22)}$$

where,

CA	=	contaminant concentration in air, $\mu g/m^3$
EC	=	exhaust shaft concentration for the VOC, $\mu g/m^3$
ADF	=	air dispersion factor, unitless

Combining equations D9-21 and D9-22 yields equation D9-15:

$$Risk = \frac{EC \times ADF \times URF \times EF \times ED}{AT}$$

Excess cancer risks to the Boundary Public Receptor are calculated using Equation D9-15 with an ADF of 1.2×10^{-4} and are presented in Table D9-3. For this assessment, excess cancer risk to the public ranges from one and one-half to three and one-half orders-of-magnitude below acceptable risk levels. All risks given in Table D9-3 are for a receptor being subjected to concentrations based on maximum exhaust shaft VOC concentrations, that is, those resulting from emissions from 9 closed and 1 full open panels, over the entire exposure period. Room closures within the open panel are not considered.

D9-5.1.2 Noncarcinogens

For noncarcinogens, excess health effects are quantified in terms of a hazard quotient. The hazard quotient is computed as:

$$Hazard\ Quotient = \frac{EC \times ADF \times EF \times ED}{AT \times RfC} \times \left(\frac{1\ mg}{1 \times 10^{3} \mu g}\right) \qquad \text{(D9-23)}$$

where,

Hazard Quotient = receptor hazard quotient, unitless
EC = exhaust shaft concentration for the VOC, $\mu g/m^3$
ADF = air dispersion factor, unitless
ED = exposure duration, years
RfC = reference concentration, mg/m^3
AT = averaging time, 306,600 hours (24 hours/day × 365 days/year × 35 years)

Note that the averaging time for noncarcinogens is one-half that for carcinogens. If the hazard quotient is below 1.0, no excess health effects to the receptor is expected. Equation D9-23 was derived from equations in EPA (1989); the derivation is shown below.

EPA (1989), page 8-11 provides the calculation for intake as:

$$Intake = Hazard\ Quotient \times RfD \qquad \text{(D9-24)}$$

where,

Intake = receptor intake, mg/kg-day
Hazard Quotient = receptor hazard quotient, unitless
RfD = reference dose, mg/kg-day

TABLE D9-3
EXCESS CANCER RISKS OUTSIDE THE WIPP SITE BOUNDARY

	Receptor Concentration (EC x ADF)	*URF*		*Risk*	
Compound	**Boundary Public Receptor (µg/m³)**	**Unit Risk Factor**	**Carcinogen Class**	**Boundary Public Receptor**	**Acceptable Risk Level**
Carbon Tetrachloride	3.79E-03	1.50E-05[a]	B2	3E-08	1E-06
Chloroform	2.17E-04	2.30E-05[a]	B2	2E-09	1E-06
1,1,-Dichloroethylene	8.34E-05	5.00E-05[a]	C	2E-09	1E-05
1,2-Dichloroethane	6.38E-05	2.60E-05[a]	B2	8E-10	1E-06
Methylene Chloride	2.45E-03	4.70E-07[a]	B2	6E-10	1E-06
1,1,2,2-Tetrachloroethane	1.03E-04	5.80E-05[b]	C	3E-09	1E-05
1,1,1-Trichloroethane	2.77E-03	1.60E-05[b]	C	2E-08	1E-05

a. Data from EPA (1994a)
b. Data from Superfund Technical Support Center

EPA (1989), page 8-5 provides the calculation for the reference dose as:

$$RfD = \frac{RfC \times IR}{BW} \qquad \text{(D9-25)}$$

where,

- RfD = reference dose, mg/kg-day
- RfC = reference concentration, mg/m^3
- IR = inhalation rate, 20 m^3/day
- BW = body weight, 70 kg

Combining equations D9-24 and D9-25:

$$Intake = \frac{Hazard\ Quotient \times RfC \times IR}{BW} \qquad \text{(D9-26)}$$

where,

Intake	=	receptor intake, mg/kg-day
Hazard Quotient	=	receptor hazard quotient, unitless
RfC	=	reference concentration, mg/m^3
IR	=	inhalation rate, 20 m^3/day
BW	=	body weight, 70 kg

Setting equations D9-15 and D9-26 equal to each other:

$$\frac{Hazard\ Quotient \times RfC \times IR}{BW} = \frac{CA \times IR \times EF \times ED}{BW \times AT} \times \left(\frac{1\ mg}{1 \times 10^3\ \mu g}\right)$$

and solving for Hazard Quotient:

$$Hazard\ Quotient = \frac{CA \times EF \times ED}{AT \times RfC} \times \left(\frac{1\ mg}{1 \times 10^3\ \mu g}\right) \qquad \text{(D9-27)}$$

where,

Hazard Quotient	=	receptor hazard quotient, unitless
CA	=	contaminant concentration in air, $\mu g/m^3$
EF	=	exposure frequency, hours/year
ED	=	exposure duration, years
AT	=	averaging time, 306,600 hours (24 hours/day × 365 days/year × 35 years)
RfC	=	reference concentration, mg/m^3

Combining equations D9-22 and D9-27 yields equation D9-23:

$$Hazard\ Quotient = \frac{EC \times ADF \times EF \times ED}{AT \times RfC} \times \left(\frac{1\ mg}{1 \times 10^3\ \mu g}\right)$$

Excess non-cancer health effects to a Boundary Public Receptor are calculated using Equation D9-23 with an ADF of 1.2×10^{-4} and are presented in Table D9-4. Non-cancer health effects range from five and one-half to six and one-half orders-of-magnitude below acceptable levels for a hypothetical Boundary Public Receptor. All hazard quotients given in Table D9-4 are a receptor being subjected to concentrations based on maximum exhaust shaft VOC concentrations, that is, those resulting from emissions from 9 closed and 1 full open panels, over the entire exposure period.

TABLE D9-4
EXCESS NON-CANCER HEALTH EFFECTS OUTSIDE THE WIPP SITE BOUNDARY

	Receptor Concentration (EC x ADF)	*RfC*	*Hazard Quotient*	
Compound	**Boundary Public Receptor (μg/m³)**	**Reference Concentration (mg/m³)**	**Boundary Public Receptor**	**Acceptable Hazard Level**
Chlorobenzene	8.88E-05	2.00E-02[a]	4E-06	1E+00
Toluene	1.15E-04	4.00E-01[b]	3E-07	1E+00

a. Data from EPA (1994b)
b. Data from EPA (1994a)

D9-5.2 Receptor Concentrations and Risk Inside the WIPP Site Boundary

The Livingston Ridge Rancher, Antelope Ridge Rancher, Surface Worker, and Underground Worker exposure scenarios are evaluated in this section. ADFs of 9.8×10^{-5}, 6.7×10^{-5}, and 1.23×10^{-2} are used for the Livingston Ridge Rancher, Antelope Ridge Rancher, and Surface Worker exposure scenarios, respectively. For all public exposure scenarios, the maximum exhaust concentration from emissions from 9 closed and 1 open panel equivalents is used in assessing risk, with no credit taken for room closures within the open panel. Room closures are used in evaluating the Underground Worker exposure scenario.

D9-5.2.1 Carcinogens

The excess cancer risks calculated for each VOC inside the WIPP site boundary for the Livingston Ridge Rancher and the Antelope Ridge Rancher are presented in Table D9-5. The excess cancer risks to the Livingston Ridge Rancher and the Antelope Ridge Rancher range from two and one-half to four and one-half orders of magnitude below acceptable levels. Acceptable levels for these receptors are 1×10^{-6} for Class B carcinogens and 1×10^{-5} for Class C carcinogens.

Risks given in Table D9-5 are for receptors being subjected to concentrations based on maximum exhaust shaft VOC concentrations, that is, those resulting from emissions from 9 closed and 1 full open panels, over the entire period of exposure.

TABLE D9-5
EXCESS CANCER RISKS INSIDE THE WIPP SITE BOUNDARY FOR LIVINGSTON RIDGE RANCHER AND ANTELOPE RIDGE RANCHER SCENARIOS

	Receptor Concentration (EC x ADF)		*URF*		*Risk*		
Compound	Livingston Ridge Rancher (µg/m³)	Antelope Ridge Rancher (µg/m³)	Unit Risk Factor	Carcinogen Class	Livingston Ridge Rancher Risk	Antelope Ridge Rancher Risk	Acceptable Risk Level
Carbon Tetrachloride	3.09E-03	2.11E-03	1.50E-05	B2	6E-09	4E-09	1E-06
Chloroform	1.77E-04	1.21E-04	2.30E-05	B2	5E-10	3E-10	1E-06
1,1,-Dichloroethylene	6.81E-05	4.65E-05	5.00E-05	C	4E-10	3E-10	1E-05
1,2-Dichloroethane	5.21E-05	3.56E-05	2.60E-05	B2	2E-10	1E-10	1E-06
Methylene Chloride	2.00E-03	1.37E-03	4.70E-07	B2	1E-10	8E-11	1E-06
1,1,2,2-Tetrachloroethane	8.45E-05	5.78E-05	5.80E-05	C	6E-10	4E-10	1E-05
1,1,1-Trichloroethane	2.27E-03	1.55E-03	1.60E-05	C	4E-09	3E-09	1E-05

TABLE D9-6
EXCESS NON-CANCER HEALTH EFFECTS INSIDE THE WIPP SITE BOUNDARY FOR LIVINGSTON RIDGE RANCHER AND ANTELOPE RIDGE RANCHER SCENARIOS

	Receptor Concentration (EC x ADF)		*RfC*	*Calculated Hazard Quotient*		
Compound	**Livingston Ridge Rancher ($\mu g/m^3$)**	**Antelope Ridge Rancher ($\mu g/m^3$)**	**Reference Concentration (mg/m^3)**	**Livingston Ridge Rancher**	**Antelope Ridge Rancher**	**Acceptable Hazard Level**
Chlorobenzene	7.25E-05	4.96E-05	2.00E-02	9E-07	6E-07	1E+00
Toluene	9.43E-05	6.45E-05	4.00E-01	6E-08	4E-08	1E+00

D9-5.2.2 Noncarcinogens

The excess non-cancer health effect calculation results for each VOC inside the WIPP site boundary are presented in Table D9-6. The ADFs used are the same as those described in Section D9-5.2.1. Excess non-cancer health effects range from six to seven and one-half orders-of-magnitude below a hazard quotient of one; this implies that there will be no adverse health effects from noncarcinogens to any of the evaluated receptors inside the WIPP site boundary. All hazard quotients given in Table D9-6 are for receptors being subjected to concentrations based on exhaust shaft VOC concentrations for emissions from 9 closed panels and 1 full open panel over the entire period of exposure.

D9-5.3 Worker Concentrations and Risk on the Surface and Underground

Worker Concentrations are calculated using the maximum allowable average VOC headspace concentration as established in Table C-5 of Chapter C. The Table C-5 limits are the highest average concentrations that can exist in any waste room. This assumption is very conservative, since the average headspace concentration clearly shows that concentrations are much lower on average. The Table C-5 limits are listed in Table D9-7.

As described in Section D-9b(4)(a) of Chapter D, occupational and public risk measures are different. For example, occupational exposure is calculated by assessing the effects on healthy adults of working age and public risk includes effects on children, adults, the elderly and the infirm. See D-9b(4)(a) for more information.

TABLE D9-7
MAXIMUM AVERAGE HEADSPACE CONCENTRATION LIMITS

Compound	Table C-5 Limit (ppmv)
Carbon Tetrachloride	7,510
Chlorobenzene	17,660
Chloroform	6,325
1,1,-Dichloroethylene	28,750
1,2-Dichloroethane	9,100
Methylene Chloride	100,000
1,1,2,2-Tetrachloroethane	7,924
Toluene	41,135
1,1,1-Trichloroethane	100,000

D9-5.3.1 Carcinogens

VOC contaminant concentrations in air for the Surface Worker and the Underground Worker are given in Table D9-8 along with Occupational Safety and Health Administration (OSHA) 8 hour time-weighted averages (TWAs). This information provides a mechanism for evaluating occupational exposures. The receptor concentrations for the Surface Worker range from four to nearly seven orders of magnitude below the TWAs. The receptor concentrations for the Underground Worker range from two to nearly six orders of magnitude below the TWAs.

Human health risk from carcinogens can be calculated using equation D9-15 with EF = 1920 hours/year for the surface worker and 33 hours per year for the underground worker, ED = 10 years, EC = ECS in Table 9-8, and ADF = 1.2×10^{-2}. The calculated risk from Carbon Tetrachloride is 9E-07 for the surface worker and 6E-07 for the underground worker. The risk from Chloroform is 9E-07 for the surface worker and 6E-07 for the underground worker. The risk from 1,1-Dichloroethene is 8E-06 for the surface worker and 5E-06 for the underground worker. The risk from 1,2-Dichloroethane is 1E-06 for the surface worker and 8E-07 for the underground worker. The risk from Methylene Chloride is 2E-07 for the surface worker and 1E-07 for the underground worker. The risk from 1,1,2,2-Tetrachloroethane is 4E-06 for the surface worker and 3E-06 for the underground worker. The risk from 1,1,1-Trichloroethane is 1E-05 for the surface worker and 8E-06 for the underground worker.

D9-5.3.2 Non-Carcinogens

As for carcinogens, noncarcinogen VOC contaminant concentrations in air for the Surface Worker and the Underground Worker and OSHA 8 hour TWAs are presented (Table D9-9). This information provides a mechanism for evaluating occupational exposures in addition to the risk assessment approach. The receptor concentrations for the Surface Worker are seven orders of magnitude below the TWAs and those for the Underground Worker are more than six orders of magnitude below the TWAs.

Human health risk from non-carcinogens can be calculated using equation D9-23 with EF = 1920 hours/year for the surface worker and 33 hours per year for the underground worker, ED = 10 years, and EC = ECS in Table 9-9. The calculated hazard quotient from Chlorobenzene is 4E-01 for the surface worker and 3E-02 for the underground worker. The risk from Toluene is the hazard quotient 3E-02 for the surface worker and 3E-03 for the underground worker.

TABLE D9-8
VOC CONTAMINANT CONCENTRATIONS IN AIR FOR THE SURFACE WORKER AND THE UNDERGROUND WORKER

			Receptor Concentration		
Compound	ECS_{max} **Exhaust Shaft Concentration for Surface Worker (μg/m^3)**	ECU_{max} **Exposure Concentration for Underground Worker (μg/m^3)**	**(ECS x ADF) Surface Worker (ppmv)**	**Underground Worker (ppmv)**	**OSHA TWA[a] (ppmv)**
Carbon Tetrachloride	1.54E+02	7.70E+01	3.00E-04	1.22E-02	10
Chloroform	1.06E+02	5.03E+01	2.67E-04	1.03E-02	50
1,1,-Dichloroethylene	4.01E+02	1.86E+02	1.24E-03	4.68E-02	5[b]
1,2-Dichloroethane	1.25E+02	6.00E+01	3.81E-04	1.48E-01	50
Methylene Chloride	1.26E+02	5.66E+02	4.45E-03	1.63E-02	500
1,1,2,2-Tetrachloroethane	1.77E+02	8.86E+01	3.17E-04	1.29E-02	5
1,1,1-Trichloroethane	1.77E+03	8.89E+02	4.00E-03	1.63E-01	350

a. 8 hour TWAs except chloroform TWA for up to a 10 hour day in a 40 hour work week.
b. TWA from ACGIH

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TABLE D9-9
VOC CONTAMINANT CONCENTRATIONS IN AIR FOR THE SURFACE WORKER AND THE UNDERGROUND WORKER

Compound	ECS_{max} Exhaust Shaft Concentration for Surface Worker (µg/m³)	ECU_{max} Exposure Concentration for Underground Worker (µg/m³)	Receptor Concentration Surface Worker (ppmv)	Underground Worker (ppmv)	OSHA TWA (ppmv)
Chlorobenzene	2.58E+02	1.32E+02	6.91E-04	2.88E-02	75
Toluene	4.99E+02	2.53E+02	1.63E-03	6.70E-02	200

D9-6 Summary

Based on estimated maximum VOC emissions from emplaced waste, there are no significant exposures expected to occur to the public or workers. Risks and hazards to members of the public range from one and one-half to seven and one-half orders-of-magnitude below acceptable levels. Worker exposure VOC concentrations are approximately two to over five orders-of-magnitude below 8 hour OSHA TWAs.

The worker exposure and public risk assessment used the following conservative assumptions:

- Table C-5 limits for headspace concentrations of VOCs represent the average container concentration
- All drums are fitted with the model NFT-013 carbon composite filter
- The effective gas generation rate is constant in closed panels
- The actual source of VOCs will exist throughout the operational/closure phase and will maintain the average concentrations in drum and panel headspaces (i.e., no depletion of the source over time)
- VOC concentrations in the closed panel atmosphere are instantaneously equivalent to the drum average headspace concentrations
- There is no decrease in closure system permeability due to creep closure over time
- The hypothetical Boundary Public receptor is exposed every hour of every day during the span of facility operations
- Public risk to developing excess cancer does not include the probability that the receptor is one of the 27 residents within 10 miles (16 kilometers) of WIPP

WIPP

- Enough moisture will exist to create humid environmental conditions for gas generation
- A full repository of waste exists for the duration of the operational/closure
- There will be 81,000 drums disposed of in each panel. The actual configuration may include 60% Standard Waste Boxes (2 vents, 7-drum equivalent) and 40% drums (1 vent), meaning less than 81,000 filter vents will be venting in a panel (approximately 58,000).
- The assessments for the public and surface worker assume that no room ventilation barriers are installed, and emissions from 9 closed and 1 open panel full of waste exists for 35 years

Other assumptions that may contribute to the overall uncertainty of the receptor concentration and risk estimates are as follows:

- The mine ventilation flow rate will remain constant throughout the operational/closure phase
- Weighted average drum headspace concentrations of VOCs are representative of all waste to be disposed of at the WIPP

Although the uncertainties in the receptor concentration and risk estimates that result from these assumptions are not quantifiable, it is believed that they are far outweighed by the conservative assumptions used in the estimates.

D9-7 REFERENCES

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ATTACHMENT 1
EXAMINATION OF ROOF COLLAPSE SCENARIO

D9-ATT 1-1.0 Background Information from WIPP SAR

An unexpected roof collapse in panels two through eight is considered to be an incredible ($\leq 10^{-6}$) accident because the panels will be mined, filled with waste, and closed before a roof fall in these panels becomes a concern (WIPP 1995). However, Panel 1, having a longer life span, has been addressed for this scenario as a special case. The WIPP safety analysis report (SAR) (WIPP 1995) determined that the unexpected roof collapse event in Panel 1 during emplacement operations in the underground bounds all other roof collapses due to the total number of waste containers in the area during these operations. Even in Panel 1, such a roof fall would require the failure of preventive and mitigative systems and controls identified in the SAR for this scenario, and is considered unlikely (frequency of occurrence of 10^{-2} to 10^{-4}).

The number of drums that can be placed under this hypothetical room collapse, stacked 3 layers high in seven pack configurations, is 3,843 (WIPP). The maximum drum weight allowed by the WIPP WAC is 1,000 pounds. Assuming the top two layers of drums in the waste stack are loaded to the maximum weight of 1,000 lb (454 kg), a loading of 2,000 pounds (907 kg) would be applied to a drum in the bottom layer. Based on the roof collapse in room 1 in the Site Preliminary Design Validation (SPDV), the section that collapsed was irregularly shaped and approximately 33 ft (10 m) wide by 7 ft (2.1 m) thick by 180 ft (54.9 m) long and weighed 700 tons (636 metric tons). With the added weight of the 7 ft (2.1 m) high collapsed roof material, the load on a drum on the bottom layer is 3,100 lb (1407 kg) (WIPP 1995). Backfill added to the top of the drum stack contributes 4200 lb (1907 kg) to each seven pack or 600 lb (272 kg) to each drum. Thus, the total load on a drum on the bottom layer is 3,700 lb (1680 kg). Conservatively assuming this entire mass as dynamic loading, the maximum load on a drum from 3,700 lb (1680 kg) of material falling a distance 1.5 ft (0.4572 m) approximately 5,550 ft-lb (7,540 N-m).

Sandia National Laboratories, in report SAND80-2157, *Analysis, Scale Modeling, and Full-Scale Tests of Low-Level Nuclear Waste Drum Response to Accident Environments* (Sandia 1980), concluded that the energy required to crush an empty drum 10 inches in the axial direction requires a dynamic load of greater than 16,947 N-m. The lid did not separate from the drum and the drum did not breach during the dynamic tests. Therefore, the roof fall scenario, when conservatively considering the dynamic effects of falling roof material on drums, is not expected to result in any breached drums.

Even if some of the drums are breached, the material falling is expected to encapsulate the waste and the material available to be released will be minimal. Therefore, no release of radioactive or nonradioactive hazardous materials is expected from the loading of drums due to the added weight of the collapsed roof material. However, for conservatism the SAR assumed that an underground roof collapse causes 21 drums to fall from the top of the stack resulting in a breach of those drums.

D9-ATT 1-2.0 Methodology

Two scenarios were evaluated: (1) a roof collapse in an open room that is being filled with drums, and (2) a roof collapse in a closed room with ventilation barriers in place. In addition two cases are evaluated for each scenario based on the concentrations of VOCs in the headspace of the drums. These cases are: (1) drum headspace VOC concentrations corresponding to the values given in Table C-5, representing the maximum average headspace concentrations for a container of waste, and; (2) concentrations of VOCs in the drum headspace corresponding to the weighted average concentrations as calculated in Appendix C2. Assumptions used to quantify exposure levels associated with the scenarios and cases examined are presented in the following sections.

D9-ATT 1-2.1 Open Room Scenario

D9-ATT 1-2.1.1 Assumptions

1) The underground roof (back) collapse may occur during waste emplacement causing 21 drums to fall from the top of the stack resulting in a breach of the drums, although the roof life has been extended by a supplementary roof support system (WIPP 1995). Two cases are examined one based on the Table C-5 limits of VOCs in the containers and the second based on the Appendix C2 headspace concentrations.

2) The room is backfilled to 1.5 ft from the ceiling (i.e., no credit is taken for the air between the drums).

3) Room dimensions are 300 ft x 33 ft x 13 ft.

4) The void space in each drum is 5.2 ft^3 (WIPP 1995).

5) The room headspace air volume and the void space gas volume in the breached containers, mix completely and instantaneously.

6) Dilution of the contaminated air from the collapsed room with the air flowing by the workers is negligible because
    a) the rate of displacement of the contaminated air is much greater than the rate of fresh air flow by the workers.
    b) the collapse of the room will preclude fresh air ventilation.

7) The contaminated air is cleared from the vicinity of the workers based on the rate of the fresh air flowing by them (i.e., 35,000 ft^3/min) (WID 1996).

8) Duration of exposure is dependent on the rate at which the contaminated air is cleared from the vicinity of the worker. Averaging time for calculation of risk and hazard quotient is 70 yrs and 0.014 hrs, respectively.

9) A worker is assumed to be downstream of this event. In reality, for as low as reasonable achievable (ALARA) reasons, few workers spend time downstream of the emplaced radioactive waste.

D9-ATT 1-2.1.2 Calculations

1) Volume of clean air in the room headspace (RHV)

300 ft (length) x 33 ft (width) x 1.5 ft (headspace) = 14,850 ft^3

2) Volume of contaminated air released from the containers (CAC)

(number of drums) x 5.2 ft^3/drum = 109.2 ft^3 (for 21 drums)

3) Concentration of the contaminant in the room air (CCR) (NOTE - the room air is hereafter referred to as the cloud)

(VOC concentration)x(CAC/(RHV+CAC)) = ppmv

4) Duration of worker exposure (DWE)

(RHV + CAC)/35,000 ft^3/min = (14,850 ft^3 + 109.2 ft^3)/35,000 ft^3 = 0.43 min

5) 8-hour time weighted average

(CCR x DWE x hr/60 min)/8 hrs

D9-ATT 1-2.2 Closed Room Scenario

The time dependent VOC concentration expressed as mole fraction VOC in a closed room may be evaluated by solving the following differential equation describing the accumulation of VOC in the sealed room due to the diffusion of VOC through the drum filter from the drum headspace into the room.

$$\frac{dX_R}{dt} = NR_f\,(X_H - X_R)$$

subject to the initial condition that no VOC is present in the closed room initially, i.e.

$X_R(t = 0) = 0$

where,

$$R_f = \frac{D_{VOC} \times R \times T}{V_{air} \times P}$$

R_f VOC filter release coefficient (1/day mol fraction)
D_{VOC} VOC diffusivity through filter on drum, mol s^{-1} mol $fraction^{-1}$
R Gas law constant, 8.2057×10^{-5} atm m^3 mol^{-1} K^{-1}
T Absolute temperature, 298 K
V_R Room headspace volume, 14,850 ft^3
P Absolute pressure, 1 atm
X_R Mole fraction VOC in the closed room, dimensionless
N Number of drums in closed room, 11,571 drums
X_H Mole fraction VOC in drum headspace, dimensionless
t Time, yr.

The solution to the differential equation yields the time dependent VOC concentration in a closed room as:

$$X_R(t) = X_H(1 - e^{-NRt})$$

The time dependent concentrations of VOCs in the closed room are presented in Figure D9-ATT 1-1, After 0.1 years, the concentrations in all regions of the room have equilibrated and the concentrations are equal to the concentrations inside the drum headspace.

D9-ATT1-2.2.1 Assumptions

1) The underground roof collapse occurs in a closed room (i.e. a room with a ventilation barrier) Six rooms are closed and each room contains 11, 751 drums. The last room is open and is about to be closed with 11,751 drums inside.

2) The room is backfilled to 1.5 ft from the ceiling.

3) Room dimensions are 300 ft x 33 ft x 13 ft.

4) Based on the previous analyses to predict VOC concentrations in a closed room as a function of time, the concentrations of the VOCs in the air gap have equilibrated with the VOC concentrations in the headspace of the containers (i.e, the VOC concentration in the room is equal to the VOC concentration in the drum headspace).

5) Based on the Sandia experiments, the collapse of the roof material onto the drum stacks does not provide sufficient energy to breach the drums. Thus, only the contaminated air gap is available for release. Based on examination of the material that collapsed in room 1 in the SPDV, the collapse of the roof material can not be simply described as a piston system that expels the contaminated air gap into the panel access drifts. The majority (90%) of the contaminated air will escape into the overlying void space created by the collapsed section and will not be available for release into the fresh air flowing through the panel. Ten percent of the room air is released with 5% escaping through each side of the room. Thus a worker is exposed to 5% of the room air.

6) In calculating the 8 hr TWA, the contaminated air is cleared from the vicinity of the worker based on the rate of the fresh air flowing by them (i.e., 35,000 ft^3/min) (WID 1996).

7) In calculatng the 8 hr TWA, the duration of exposure is dependent on the rate at which the contaminated air is cleared from the vicinity of the worker and is calculated based on 5% of the contaminated air being released into the fresh air flowing through the access drift in the panel.

8) A worker is assumed to be downstream of this event. In reality, for as low as reasonable achievable (ALARA) reasons, few workers spend time downstream of the emplaced radioactive waste.

D9-ATT 1-2.2.2 Calculations

1) Duration of worker exposure (DWE) is calculated as

$$(f \times RHV)/(35{,}000\ ft^3/min)$$

where,

f	Fraction of room headspace volume that is released to an access drift and available for worker exposure, 0.05 dimensionless

RHV	Room headspace volume, 14,850 ft^3

2) The 8-hour time weighted average (TWA) assuming one closed room with a roof collapse is calculated as:

(CCR x DWE xhr/60 min)/8 hr

where,

CCR	Concentration of the contaminant in the room air, ppmv

3) The maximum 1-minute concentration that the worker is exposed to is calculated as:

MAXC = CCR x f x RHV/(35,000 ft^3 + f x RHV)

D9-ATT 1-3.0 Discussion

The VOC concentrations to which the workers would be exposed in the scenarios examined were compared to various exposure limits, including threshold limit values (TLVs), permissible exposure limits (PELs), and recommended exposure limits (RELs). These exposure limits were compiled from various sources and are presented in Table D9-Att 1-1.

D9-ATT 1-3.1 Open Room Scenario

The calculated worker exposures, given as the contaminant concentration in the cloud (CCR), were then compared to the most restrictive exposure limits; this comparison is presented in Table D-ATT 1-2 and Table D9-Att 1-3 for each of the two examined. Based on the analyses, the immediate VOC concentrations in air (i.e., in the CCRs) are below the respective IDLH exposure limits for both of the scenarios. The 8-Hr TWA concentrations are below the respective TWA exposure limits for both of the scenarios.

D9-ATT 1-3.2 Closed Room Scenario

The calculated worker exposures, in terms of 8 hr TWA concentrations were then compared to the most restrictive exposure limits. This comparison is presented in Table D9-ATT 1-4 and Table D9-ATT 1-5 for each of the two cases examined. Based on the Table C-5 limits for VOCs in the drum headspace, the 1 minute maximum VOC concentrations are below the IDLH limits for all VOCs. Using the Table C-5 VOC concentrations in the drum headspace, the 8 Hr TWA are below the 8 Hr TWA limits. Based on the Appendix C2 concentrations for VOCs in the drum headspace, the 1 minute maximum concentrations are well below the IDLH values in all cases and the calculated worker exposure 8 hr TWA concentrations are well below the 8 hr TWA limits.

REFERENCES

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TABLES

Table D9-ATT 1-1. Exposure Limits[a]

Substance	OSHA PEL[b]	ACGIH TLV	NIOSH REL[c]
Carbon tetrachloride (Tetrachloromethane)	10 ppm TWA (C) 25 ppm 200 ppm peak for 5 min in any 4 hrs	5 ppm TWA, 31 mg/m^3 10 ppm STEL, 63 mg/m^3 Animal carcinogen	2 ppm STEL (60 min), 12.6 mg/m^3 Carcinogen 200 ppm IDLH
Chlorobenzene	75 ppm TWA, 350 mg/m^3	10 ppm TWA, 46 mg/m^3	NL[d] 1,000 ppm IDLH
Chloroform (Trichloromethane)	(C) 50 ppm, (C) 240 mg/m^3	10 ppm TWA, 49 mg/m^3 Suspected human carcinogen	NL[e] 2 ppm STEL (60 min), 9.78 mg/m^3 Carcinogen 500 ppm IDLH
1,1-Dichloroethylene (Vinylidene chloride)	NL	5 ppm TWA, 20 mg/m^3 20 ppm STEL, 79 mg/m^3	NL[e] Carcinogen IDLH not determined
1,2-Dichloroethane (Ethylene dichloride)	50 ppm TWA (C) 200 ppm 300 ppm peak for 5 min in any 3 hrs	10 ppm TWA, 40 mg/m^3	NL[e,f] 1 ppm TWA, 4 mg/m^3 2 ppm STEL, 8 mg/m^3 Carcinogen 50 ppm IDLH
Methylene chloride (Dichloromethane)	500 ppm TWA (C) 1,000 ppm 2,000 ppm peak for 5 min in any 2 hrs	50 ppm TWA, 174 mg/m^3 Suspected human carcinogen	NL[e] Carcinogen 2,300 ppm IDLH
1,1,2,2-Tetrachloroethane	5 ppm TWA, 35 mg/m^3 Skin designation	1 ppm TWA, 6.9 mg/m^3 Skin designation	NL[e,f] 1 ppm TWA, 7 mg/m^3 Carcinogen, skin designation 100 ppm IDLH
Toluene	200 ppm TWA (C) 300 ppm 500 ppm peak for 10 min	50 ppm TWA, 188 mg/m^3 Skin designation	100 ppm TWA, 375 mg/m^3 150 ppm STEL, 560 mg/m^3 500 ppm IDLH
1,1,1-Trichloroethane (Methyl chloroform)	350 ppm TWA, 1,900 mg/m^3	350 ppm TWA, 1,910 mg/m^3 450 ppm STEL, 2,460 mg/m^3	(C) 350 ppm (15 min), (C) 1,900 mg/m^3 700 ppm IDLH

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Substance	OSHA PEL[b]	ACGIH TLV	NIOSH REL[c]

[a]SOURCE: 29 CFR 1910.1000; ACGIH 1995; NIOSH 1994.
[b]8 hr TWA unless noted otherwise, (C) denotes ceiling limit
[c]Up to a 10 hr day in a 40 hr workweek TWA, STEL is a 15 min TWA unless noted otherwise
[d]NIOSH questions whether the OSHA PEL TWA of 75 ppm is adequate to protect workers from recognized health hazards but does not offer an alternative.
[e]NIOSH usually recommends that occupational exposures to carcinogens be limited to the lowest feasible level
[f]NIOSH considers the substance to be a potential occupational carcinogen

Acronyms and Units for Table D9-ATT 1-1

OSHA	Occupational Safety and Health Act
PEL	permissible exposure limit
ACGIH	American Conference of Governmental Industrial Hygienists
TLV	threshold limit value
NIOSH	National Institute for Occupational Safety and Health
REL	recommended exposure limit
ppm	parts of vapor or gas per million parts of contaminated air by volume at 25C and 760 torr
TWA	time-weighted average
(C)	ceiling limit
STEL	short-term exposure limit
IDLH	immediately dangerous to life or health concentration
mg/m^3	milligrams per cubic meter
NL	not listed

Table D9-ATT 1-2. Open Room Scenario: Comparison of Calculated Cloud Concentrations from 21 Drum Source and Table C-5 VOC Concentrations to Most Restrictive Exposure Limits

Chemical	Headspace Table C-5 Limit VOC Concentration (ppm)	Concentration in Air (ppm)		Exposure Limit (ppm)	Source
		Immediate	8-Hr TWA		
Carbon tetrachloride	7,510	27.51	0.05	2 (STEL) 5 (TWA) 200 (IDLH)	NIOSH ACGIH NIOSH
Chlorobenzene	-	--[a]	--	10 (TWA) 1000 (IDLH)	ACGIH NIOSH
Chloroform	6,325	23.17	0.04	2 (STEL) 10 (TWA) 500 (IDLH)	NIOSH ACGIH NIOSH
1,1-Dichloroethylene	28,750	105.3	0.19	20 (STEL) 5 (TWA)	ACGIH ACGIH
1,2-Dichlihoroethane	9,100	33.34	0.06	2 (STEL) 1 (TWA) 50 (IDLH)	NIOSH NIOSH NIOSH
Methylene chloride	100,000	366.3	0.65	50 (TWA) 2,300 (IDLH)	ACGIH NIOSH
1,1,2,2-Tetrachloroethane	-	--	--	1 (TWA) 100 (IDLH)	NIOSH NIOSH
Toluene	-	--	--	150 (STEL) 50 (TWA) 500 (IDLH)	NIOSH ACGIH NIOSH
1,1,1-Trichloroethane	-	--	--	450 (STEL) 350 (TWA) 700 (IDLH)	ACGIH ACGIH NIOSH

a No Table C-5 limit assigned.

Table D9-ATT 1-3. Open Room Scenario Comparison of Calculated Cloud Concentrations from 21 Drum Source and Appendix C2 VOC Concentrations to Most Restrictive Exposure Limits

Chemical	Appendix C2 Headspace VOC Concentration (ppm)	Concentration in Air (ppm)		Exposure Limit (ppm)	Source
		Immediate	8-Hr TWA		
Carbon tetrachloride	375.5	1.38	2.44×10^{-3}	2 (STEL) 5 (TWA) 200 (IDLH)	NIOSH ACGIH NIOSH
Chlorobenzene	12.5	0.05	8.13×10^{-5}	10 (TWA) 1000 (IDLH)	ACGIH NIOSH
Chloroform	25.3	0.09	1.64×10^{-4}	2 (STEL) 10 (TWA) 500 (IDLH)	NIOSH ACGIH NIOSH
1,1-Dichloroethylene	11.5	0.04	7.48×10^{-5}	20 (STEL) 5 (TWA)	ACGIH ACGIH
1,2-Dichloroethane	9.1	0.03	5.92×10^{-5}	2 (STEL) 1 (TWA) 50 (IDLH)	NIOSH NIOSH NIOSH
Methylene chloride	368.5	1.35	2.40×10^{-3}	50 (TWA) 2,300 (IDLH)	ACGIH NIOSH
1,1,2,2-Tetrachloroethane	9.4	0.03	6.11×10^{-5}	1 (TWA) 100 (IDLH)	NIOSH NIOSH
Toluene	19.4	0.07	1.26×10^{-4}	150 (STEL) 50 (TWA) 500 (IDLH)	NIOSH ACGIH NIOSH
1,1,1-Trichloroethane	317.1	1.16	2.06×10^{-3}	450 (STEL) 350 (TWA) 700 (IDLH)	ACGIH ACGIH NIOSH

Table D9-ATT 1-4. Closed Room Scenario Comparisons of Concentrations Based on Table C-5 VOC Concentration Limits to the Most Restrictive Exposure Limits

VOC	Table C5 VOC Concentration Limit (ppmv)	Calculated 8 Hr TWA (ppmv)	Maximum 1 min Concentration (ppmv)	IDLH	8 Hr TWA Limits (ppmv)
Carbon tetrachloride	7,510	0.33	156	200	5
Chlorobenzene	-	-	-	-	10
Chloroform	6,325	0.28	131	500	10
1,1-Dichloroethylene	28,750	1.27	597	-	5
1,2-Dichloroethane	9,100	0.40	189	50	1
Methylene chloride	100,000	4.42	2,080	2,300	50
1,1,2,2 Tetrachloroethane	-	-	-	100	1
Toluene	-	-	-	500	50
1,1,1,1-Trichloroethane	-	-	-	700	350

Table D9-ATT 1-5. Closed Room Scenario Comparisons of Concentrations Based on Appendix C2 Weighted Average Headspace Concentrations to the Most Restrictive Exposure Limits

VOC	Appendix C2 VOC Concentration (ppmv)	Calculated 8 Hr TWA (ppmv)	Maximum 1 min Conc. (ppmv)	IDLH	8 Hr TWA Limits (ppmv)
Carbon tetrachloride	376	0.0166	7.80	200	5
Chlorobenzene	13	0.0006	0.26	-	10
Chloroform	25	0.0011	0.53	500	10
1,1-Dichloroethylene	12	0.0005	0.24	-	5
1,2-Dichloroethane	9	0.0004	0.19	50	1
Methylene chloride	369	0.0163	7.66	2,300	50
1,1,2,2-Tetrachloroethane	9	0.0004	0.20	100	1
Toluene	19	0.0009	0.40	500	50
1,1,1,1-Trichloroethane	317	0.0140	6.59	700	350

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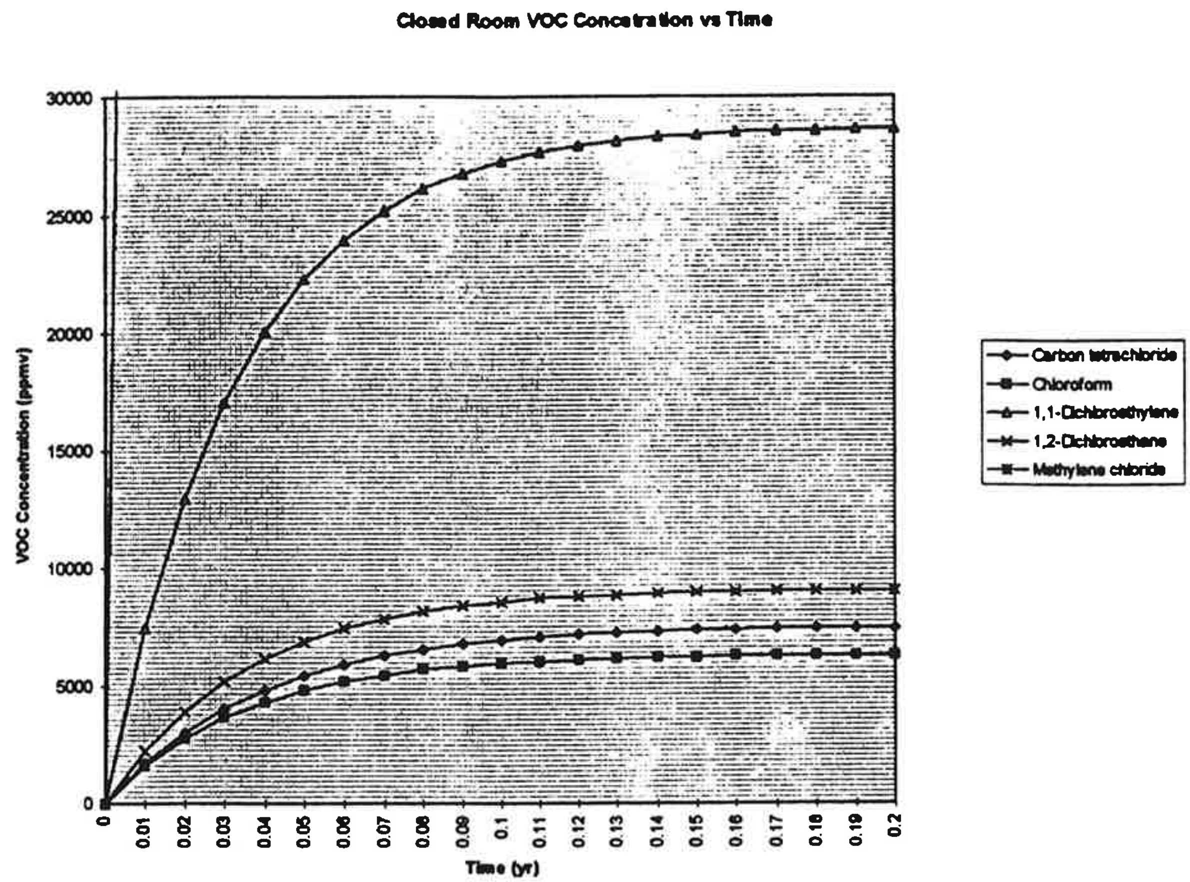

Figure D9-ATT 1-1 Closed Room VOC Concentration Versus Time