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MT Dept. of Environmental Quality
Permitting & Compliance Division / Air Resources Management

MINES MANAGEMENT INC.
MONTANORE MINE
APPLICATION FOR AIR QUALITY PRECONSTRUCTION PERMIT

Prepared for:

Montana Department of Environmental Quality
Helena, Montana

Prepared by:

TRC Environmental Corporation
605 Skyline Drive
Laramie, WY 82070

Mines Management, Inc.
905 Riverside Ave., Ste. 311
Spokane, WA 99201

January 9, 2006

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TRC Project No. 46706
January 9, 2006

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1.0 INTRODUCTION

Mines Management Inc. (Mines Management) proposes to construct and operate the Montanore Mine, a 20,000-ton per day (tpd) underground silver and copper mine and mill facility to be located in Lincoln County 15 miles south-southwest of Libby. TRC Environmental Corporation (TRC) has been contracted by Mines Management to prepare this minor source air quality permit application pursuant to ARM Title 17 Chapter 8 Subchapter 7.

The application includes a project description (Chapter 2), emissions inventory (Chapter 3), ambient air quality analysis (Chapter 4), and additional compliance demonstrations required or requested by MDEQ (Chapter 5). MDEQ permit application forms are contained in Appendix A.

The contact for information and questions regarding this permit application is:

Mr. Eric Klepfer
Vice President Environmental Affairs
Mines Management Inc.
905 W. Riverside Ave, Ste. 311
Spokane, WA 99201
(509) 838-6050

1.1 Project Background

The Montanore Mine, under different ownership, received an air quality preconstruction permit from MDEQ in 1989 (TRC 1989). The facility as permitted in 1989 was not constructed. Mines Management has revised mine design and facility operating specifications from those originally proposed. These revisions, combined with contemporary inventory and analysis methods, result in the stand-alone permit application herein.

A modeling protocol (Protocol) (TRC 2005a) was submitted to MDEQ on September 27, 2005. MDEQ provided comments on the protocol on October 11, 2005 (MDEQ 2005a). TRC responded to those comments on December 12, 2005 (TRC 2005b), and MDEQ replied to comment responses on December 20, 2005 (MDEQ 2005b). The methodology defined in the protocol is reflected in the ambient air analysis presented in Section 4.0 of this document. The

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modeling protocol and subsequent comment and response documentation are included as Appendix B of this document.

1.2 Regulatory Applicability

A site location map illustrating the general location of Montanore Mine facilities is provided in Figure 1.1. The Montanore Mine production and processing facilities are located in an area designated as attainment for all regulated pollutants. The concentrate rail loading facility in Libby, MT is located in a nonattainment area for PM_{10} and $PM_{2.5}$. The Montanore Mine is not a categorical source, and total stationary source emissions of any criteria pollutant are less than 250 tpy; therefore, the Montanore Mine will be classified as a minor source under Prevention of Significant Deterioration (PSD) regulations. Total emissions from point sources underground and on the surface are less than 100 tpy for any criteria pollutant, less than 10 tpy for any single Hazardous Air Pollutant (HAP), and less than 25 tpy for total HAPs; therefore, the Montanore mine will not meet the major source definition set forth in ARM 17.8.1201(23), will be a minor source, and will not require a Title V operating permit under ARM 17.8.12.

The project emits greater than 25 tons per year of any regulated pollutant; therefore, pursuant to 17.8.743(1)(e) an air quality permit must be obtained in accordance with permit requirements as outlined in ARM 17.8.7, "Permit, Construction and Operation of Air Contaminant Sources".

The project will demonstrate compliance with all applicable State and Federal regulations. A summary of applicable regulations addressed in this document and the location of the data provided within this document to comply with them are summarized in Table 1.1.

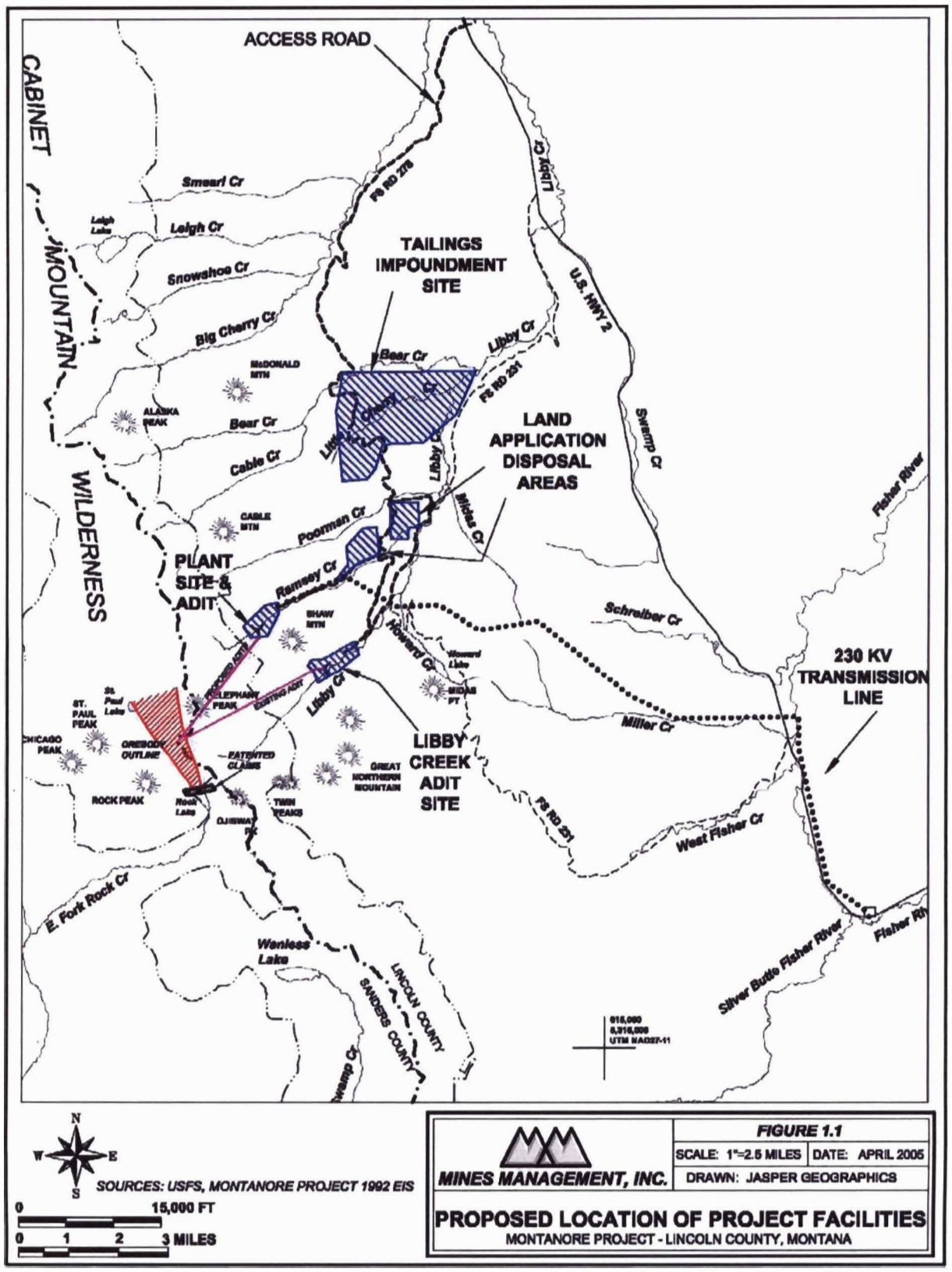

Figure 1.1 Montanore Mine Site Location

Table 1.1
Applicable Regulations and Permit Requirements

Regulation	Citation	Location
Air quality permit application required	ARM 17.8.743	Application data contained herein
Air quality permit application fees	ARM 17.8.504(1)	Attached
Certification Statement	ARM 17.8.748(3)	Appendix A
Facility map and diagram	ARM 17.8.748(4)(a)	Figure 2.1, 2.2, 2.3
Project description	ARM 17.8.748(4)(b)	Section 2.0
Control equipment description	ARM 17.8.748(4)(c)	Section 3.0
Stack parameters and emission rates	ARM 17.8.748(d)	Table 4.1
Operating schedules	ARM 17.8.748(e)	Section 2.1
Air pollution control equipment specifications	ARM 17.8.748(f)	Section 3.5
Construction schedule	ARM 17.8.748(g)	Section 2.2
Additional information requested by MDEQ	ARM 17.8.748(j)	Section 4.0 Section 5.0
BACT and emission control requirements	ARM 17.8.752	Section 3.0
Modeled demonstration of compliance	ARM 17.8.749(3)	Section 4.0
Compliance with ambient standards for SO_2, NO_2, CO, lead, and PM_{10}	ARM 17.8.210, 211, 212, 222, 223	Section 4.0
GEP stack height limitation	ARM 17.8.402	Section 5.2
Visible particulate (opacity) limits	ARM 17.8.304(2)	Section 5.1 Section 5.3
Airborne particulate limits	ARM 17.8.308	Section 5.1 Section 5.3
Particulate limits in fuel burning and industrial equipment	ARM 17.8.309 ARM 17.8.310	Section 5.3
Sulfur content in fuel limits	ARM 17.8.322	Section 5.3
Open burning	ARM 17.8.601	Section 5.4
New Source Performance Standards	40 CFR, Part 60 ARM 17.8.767(e)	Section 5.1

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2.0 PROJECT DESCRIPTION

2.1 Project Description

The Montanore Mine will produce 20,000 tons per day of copper and silver ore from the mine site to be located approximately 15 miles south-southwest of Libby, in Lincoln County, MT, as shown in Figure 1.1. Access to the mine site will be via US Forest Service Road 278. The legal location of the mine can be found in Section 1 of the permit application forms. The ore deposit will be mined using conventional room-and-pillar methods, with both diesel and diesel-electric underground equipment. Mining will occur 24 hours per day, seven days per week, 365 days per year yielding approximately 7 million tons of ore annually at full production. Two buses will transport three shifts per day from the port authority at the edge of Libby, MT to the Ramsey portal.

Two mine portals, one in the Ramsey Creek drainage (Ramsey portal) and one in the Libby Creek drainage (Libby portal) will exhaust ventilation air from the underground mine and provide mine access. Ore will be crushed underground by a primary crusher and brought to the surface via conveyor through the Ramsey portal. The ore will travel from the portal to the coarse ore stockpile, then from the stockpile to a classifier/oversize crushing/screening train via underground apron feeders, and then transferred to a Semi-Autogenous Grinding (SAG) mill. Dust emissions from these ore handling activities will be controlled with water sprays, wet Venturi scrubbers, and enclosures. A detail drawing of the mill facility and surrounding operations is included as Figure 2.1. Figure 2.2 provides a flow diagram of mill facility operations.

The mill will undergo commissioning by the vendor/contractor for 30 to 60 days after start-up, during which time the mine will not yet be at full production, and all emission controls at the mill will be operational. Mines Management will take possession of the mill following completion of the commissioning process. The mill will operate 24 hours per day, seven days per week, 350 days per year. The mill will be powered by underground electric utility lines, and no continuous on-site power generation will be needed. Two diesel electric generators (one primary, one standby) will be located on-site for emergency backup use. Ore grinding operations

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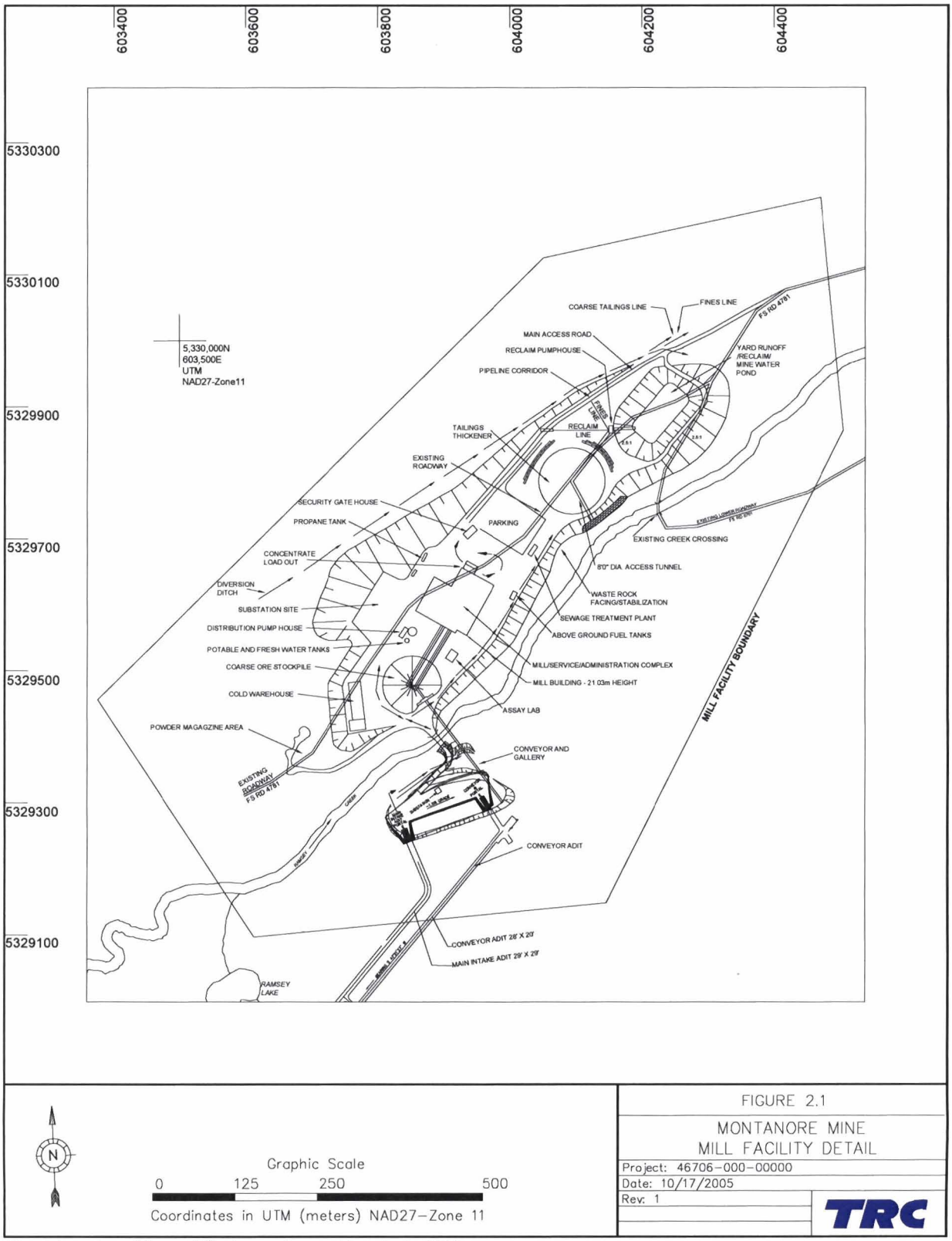

Figure based on "Figure 17", Jasper Geographics, April, 2005.

Figure 2.1 Montanore Mine Mill Facility Detail

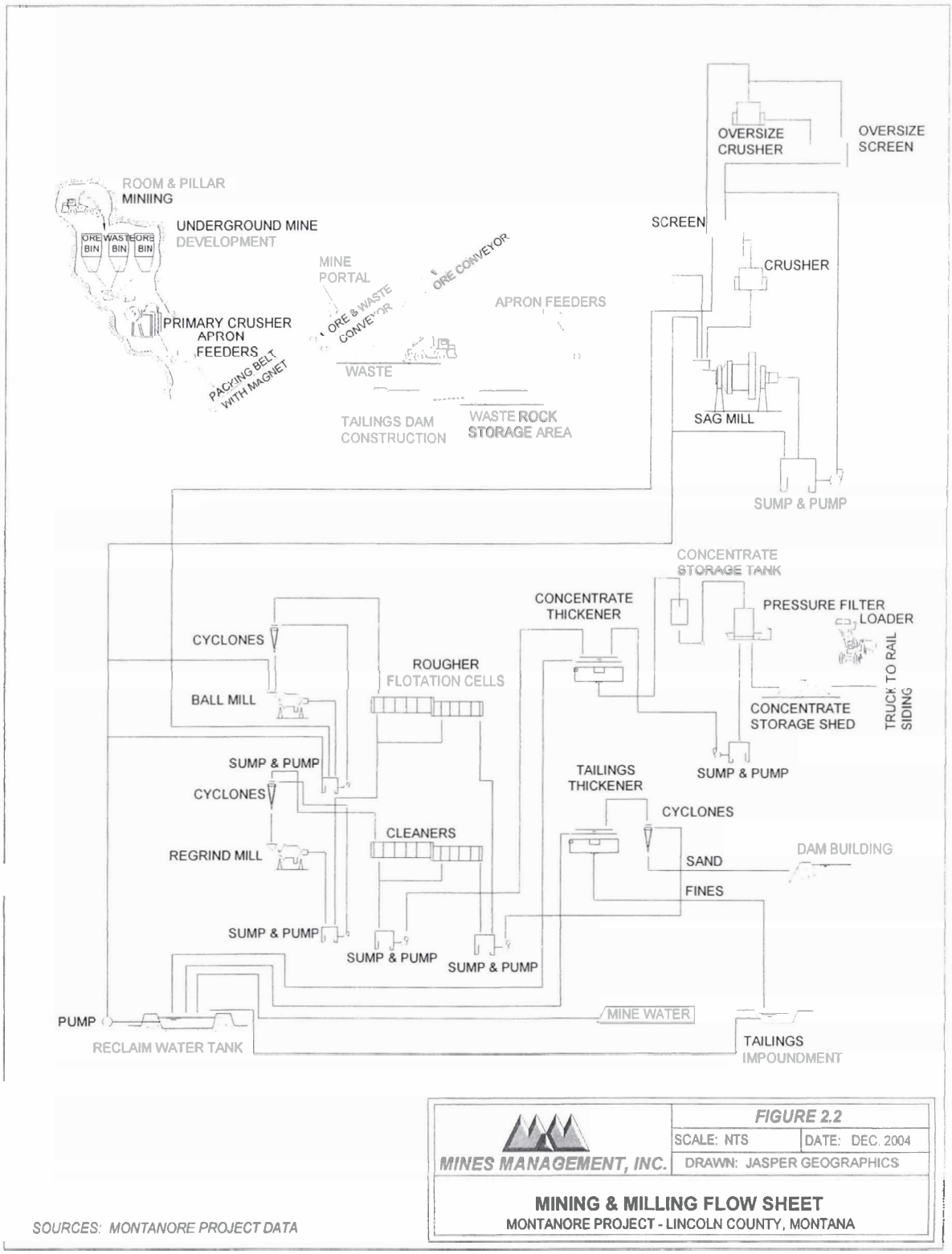

Figure 2.2 Montanore Mine Mill Flow Diagram

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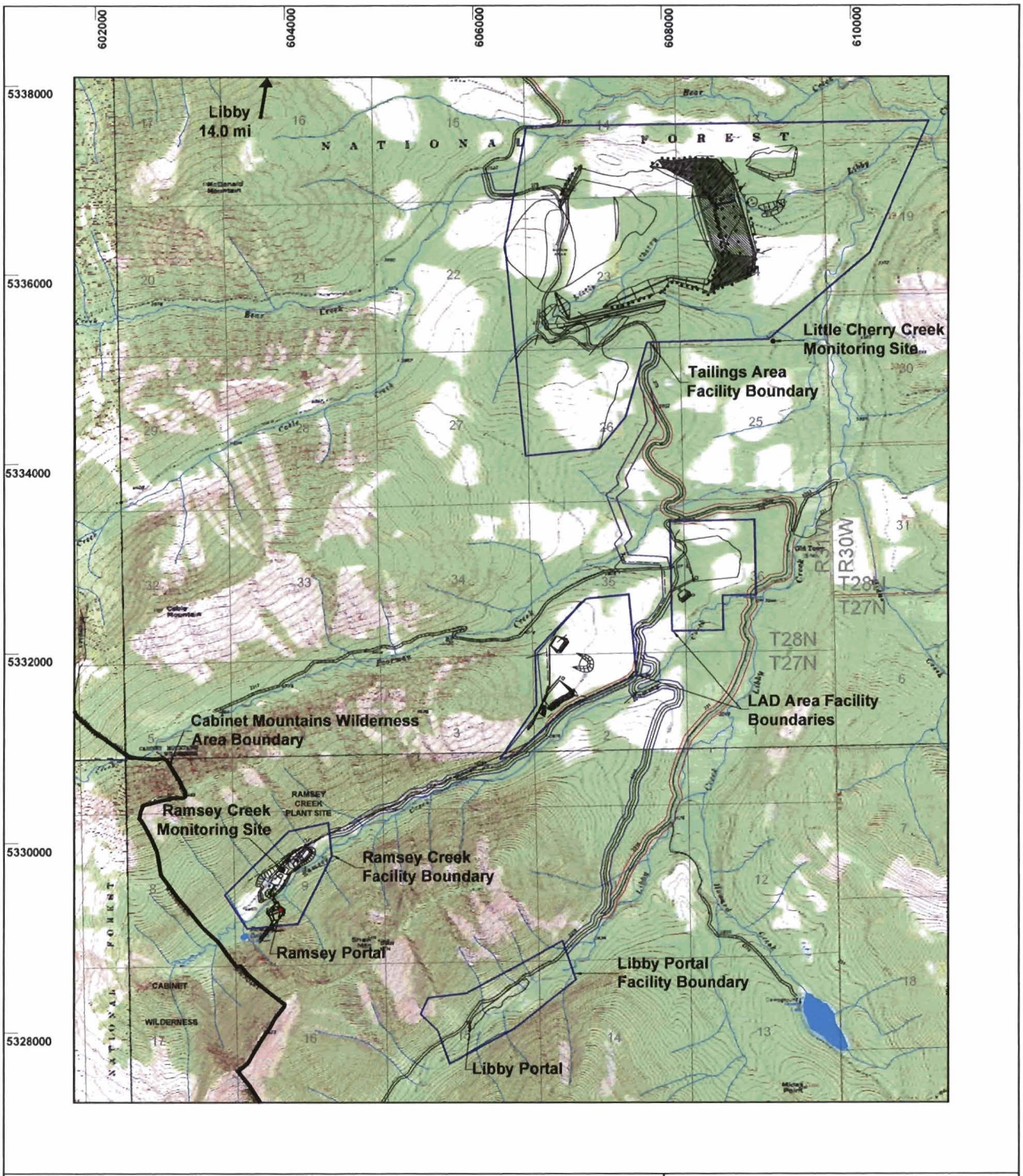
at the SAG mill will be wet and fully enclosed; therefore, the mill will not be a source of air emissions. Copper and silver values will be separated from the ore by conventional flotation techniques. The resulting concentrates will be thickened and pressure filtered to remove excess water, and transported by truck to a rail siding in Libby.

All transfer operations and storage areas at the Libby rail siding will be completely enclosed. Concentrate transported by haul truck to the Libby siding will be dumped to an enclosed storage bin which will transfer the concentrate to rail cars. Loaded rail cars waiting for consolidation into a unit train will be covered to prevent wind losses. When a sufficient number of railcars have been loaded, they will be coupled to a mainline engine for transport off-site. Accumulation of concentrate along the haul truck turn-around, at the concentrate storage area, and along the trackage will be prevented by prompt and routine clean-up with sweepers.

The tailings from the mill will be slurried through a pipeline to a tailings impoundment site located on Little Cherry Creek. Excess water will be returned to the mill for re-use. Although the tailings will be wetted with a sprinkler system, some drying may occur in the summer months. Water sprays will be used, as needed, to prevent excess fugitive dust at the tailings impoundment. The location of the tailings impoundment, Ramsey portal, Libby portal, and other major mine facilities are shown in Figure 2.3.

During mine development, some waste rock will be transported by truck from the Ramsey portal to a temporary storage area east of the mill site. This waste rock will be used as a construction material for the tailings dam and mill site areas. Subsequently, waste rock generated in the advancement of the mine will remain underground.



N

Graphic Scale
0 500 1000 1500 2000 3000
Coordinates in UTM (meters) NAD27-Zone 11

Note: No schools are located within 3,000 feet of any facility boundary.
North arrow represents true north.

FIGURE 2.3

MONTANORE MINE
FACILITY LAYOUT

Project: 46706-000-00000
Date: 10/5/2005
Rev: 0

TRC

Figure based on "Draft Figure", Jasper Geographics, March, 2005.

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2.2 Construction Schedule

The construction and operation schedule for the Montanore mine will consist of several phases:

- The first phase of construction will persist for approximately 12 months. During this phase, access roads will be upgraded, the Libby tunnel will be advanced, and an underground electric transmission line to the Libby site will be installed. No major surface construction will occur. One diesel generator (with a second co-located stand-by unit) will operate full-time during this phase until line power to the Libby site is complete, within 12 months of commencement of construction. Once the Libby underground transmission line is operational, the generators will be used on an emergency basis only.
- The second phase of construction, Ramsey development, will persist for 6 months. During this phase, the Ramsey tunnel will be advanced, roads to portals and tailings impoundment will be constructed, and Ramsey site preparation will begin.
- In additional phases of construction, surface facilities such as the mill and support facilities will be constructed, the electric transmission line to the Ramsey portal will be constructed, the tailings impoundment will be constructed, and advancement of both the Libby and Ramsey tunnels will continue. Initial mining and milling will take place during the first two years of mine life. During this time period, construction will continue as well as limited production with up to 15,700 tons per day of ore being mined and milled. Once line power to Ramsey is complete, the underground line to Libby will provide backup power to all facilities. The diesel generators will remain on-site at the Ramsey mill area to provide emergency power in the event of primary and secondary line power failure.
- Full production of 20,000 tpd of ore removal and processing will take place at approximately year four.

Production mining will continue for approximately 15 years after full development at a rate of 7 million tons per year.

3.0 EMISSIONS INVENTORY

An inventory of air pollutant emissions for point, fugitive, and mobile sources was conducted for production activities at the Montanore Mine. Emissions of NO_x, CO, SO_2, PM_{10}, $PM_{2.5}$, and trace metals including antimony, arsenic, cadmium, chromium, and lead were calculated. For all sources and pollutants, maximum hourly and/or daily and annual average emission rates were calculated. This differentiation applies most specifically to emission sources for which annual operating limits are proposed, but have the potential to operate at maximum load on an hourly and/or 24-hour basis. For these sources, short-term and long-term operating parameters utilized in emission calculations are given in the respective calculation. Mine construction will commence and the mine will phase-in production, reaching full production in operating year 4. Operations for year 4, the first year of maximum production, are considered the worst-case production emissions scenario and are examined here.

Although mobile sources and laboratory equipment are not permitted by MDEQ per ARM 17.8.744(b), emissions for these sources are calculated in this application for inclusion in the dispersion modeling analysis. Mobile source emissions are calculated from haul trucks transporting ore to the rail siding load-out facility in Libby, MT; however, because the facility will be completely enclosed, no particulate emissions will occur from transfer, storage, or loading activities at that site.

Emissions of PM_{10}, $PM_{2.5}$, NO_x, CO, and SO_2 from mine production operations were calculated using AP-42, manufacturer's emission data, or other accepted engineering methods in combination with material throughputs, equipment operating rates, and other mine operations data. Emissions of trace metals (antimony, arsenic, cadmium, chromium) classified as Hazardous Air Pollutants (HAPs), which may be present in the ore, concentrate, and tailings were calculated. Particulate emissions from the material, transfer, and storage of these materials were multiplied by the mass fractions of metals in the ore or tailings, based on assay results from the nearby Troy Mine, as reported in the Air Quality Permit Application for Asarco's Rock Creek Project (TRC 1987). Emissions of lead, also a HAP, were calculated based on preliminary ore assays reported in the Air Quality Permit Application for Noranda's Montanore Project, Volume I Permit Application (TRC 1989).

3.1 Point Sources

- Propane Heaters - Emissions from the propane heaters used to heat the mine are based on emission factors found in AP-42. Emissions are based on 151 days of operation and a maximum of 347,900 gallons of propane combusted per year in the heaters.

- Primary Crushing – Emissions from the primary crushers located underground are based on emission factors found in AP-42. Emissions are based on 20,000 tpd of ore and 700 tpd of waste rock processed by the crushers. Water sprays at the primary crushers will effect a 90% control efficiency.

- Coarse Ore Conveyor Transfers – Emissions from underground conveyor transfers are based on emission factors found in AP-42. Emissions are based on 20,000 tpd of ore brought from the primary crushers to the surface with 5 transfers occurring along the conveyor system. Water sprays at all transfers will effect a 90% control efficiency.

- Crushing/Screening – Emissions associated with all transfer points in the ore handling process were estimated using factors found in AP-42. Emissions are based on 20,000 tpd of ore to the mill, with 1,000 tpd being routed through the oversize crushing and screening train and 420 tpd of concentrate being loaded for shipment to the rail siding in Libby. Water sprays will effect a control efficiency of 90%, wet scrubbers will effect a control efficiency of 95%, and enclosures will effect a control efficiency of 99% at emission points equipped with these controls as shown in Appendix C.

- Laboratory Crusher – Emissions associated with the laboratory crusher were estimated using factors found in AP-42. Emissions are based on 1 tpd of throughput.

- Emergency Generator – Emissions from one 1622-hp diesel-fired emergency generator operating a maximum of 4 hours per calendar quarter were calculated using NO_x, CO, VOC and PM emission factors provided by the manufacturer. SO_2 emissions were calculated using fuel sulfur content. HAP emissions were not calculated for the unit

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because no manufacturer's data was available, and AP-42 emission rates in Table 3.4-3 were small and have been assigned an "E" rating by EPA, the lowest rating possible.

3.2 Fugitive Sources

- Blasting – Emissions from blasting that will occur underground are based on factors found in AP-42 and manufacturer's data specific to the explosive to be used. Emissions are based on 3,750 "Topslice" blasts per year at 800 square feet of face per blast, as well as 700 "Bench" and "Development" blasts per year each at 800 and 600 square feet per blast, respectively. All blasts will consume an estimated 4,770.5 tpy of RU Emulsion explosive, for which manufacturer's data were used for gaseous emissions, as well as 5 tpy of high explosive, for which emissions were based on AP-42 emission factors.

- Coarse Ore Stockpile Wind Erosion – Emissions from the coarse ore stockpile due to wind erosion were found to be negligible based on equations in AP-42 and the size of the coarse ore.

- Haul Truck Travel – Emissions from haul truck travel from the concentrate loadout to the rail siding in Libby are based on AP-42. Emissions are based on 21 round-trips per day at a distance of 40 miles per round-trip.

- Tailings Impoundment Wind Erosion – Emissions were calculated using a maximum erodible surface area of 400 acres, based on engineering estimates that 50% of the 800-acre impoundment size will be submerged at any time. Operation of a sprinkler system will control wind erosion on the non-submerged portions of the impoundment; this control method was not accounted for in wind erosion emission calculations and the 400 acre area was conservatively assumed to be dry and to be disturbed every hour. Emissions from the tailings impoundment due to wind erosion are based on equations and data found in AP-42 Section 13.2.5, Industrial Wind Erosion (EPA 1985). TRC has developed Fortran code which performs the hour-by-hour calculations using ISC ASCII formatted meteorological data. The output from this program, as well as the Fortran code and executable file, are included electronically in Appendix G. A copy of the program

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output showing inputs to the industrial wind erosion equation are provided in Appendix C. Hourly Ramsey Creek meteorological data were used in the calculations. Although the Little Cherry Creek is nearer to the tailings site, the Ramsey Creek data was used because it is of higher quality and exhibits higher wind speeds (and thus higher potential for wind erosion) than the Little Cherry Creek data. A conservative friction velocity of 0.55 and corresponding roughness height of 0.01 cm (for ground coal surrounding coal pile at a western surface coal mine) were selected from AP-42 Table 13.2.5-2 as a conservative estimate for the tailings impoundment. Emissions control from water application was not applied to the emission calculations. Even with a low representative friction velocity, no hours exceeded the threshold wind speed which is reflective of generally low wind speeds measured at both Ramsey and Little Cherry Creek. Because no hours exceeded the threshold wind speed, potential wind erosion emissions from the tailings impoundment were zero.

3.3 Mobile Sources

Mobile equipment will operate both above and below ground. The make and model of mobile equipment reflect those planned at this time; a different make or model of equivalent capacity may be purchased based on cost or availability at the time of purchase.

All mobile source emissions were calculated based on manufacturer's engine specific data, manufacturer's Tier 2 certifications, MOBILE6, and engineering estimates where appropriate. Manufacturer's data was used if available, otherwise Tier 2 standards were used. Tier 2 standards likely overestimate emissions since underground mining equipment is typically clean burning. MOBILE6 was used to calculate emissions from "on-highway" light duty pickups used at the mine site. For SO_2 emissions, a sulfur balance was used on engines for which no manufacturer's data was available. Sulfur content in diesel fuel was based on EPA limits which will become effective in 2007.

Emissions were based on the estimated daily operating schedule of each piece of equipment. A 40% load factor was applied to equipment to account for average engine load during the time equipment is operating (Mudd 1968). An equipment availability factor of 57.95% was

developed by Mines Management. The derivation of the availability factor, which accounts for equipment maintenance, downtime, and other factors, is described in the detailed emissions calculation sheets. Detailed emissions calculations for mobile sources are provided in the emissions inventory in Appendix C.

3.4 Emission Controls

Emission controls to be utilized at the Montanore Mine are described below. These controls constitute BACT, as required by ARM 17.8.752(1)(a). Mines Management will operate all equipment proposed in this application to provide for maximum air pollution control for which it was designed in accordance with ARM 17.8.752(2).

All underground and surface material transfers and material processing equipment/activities will be equipped with emission controls to limit particulate emissions. As shown in the emissions descriptions above and in the detailed emissions calculations in Appendix C, particulate will be controlled from 90% to 99% at these sources, depending upon the technology utilized. Moisture content in mined ore is also anticipated to be high which will inherently control particulate emissions.

Water sprays (90% control) are utilized at underground crushing and transfers, and above ground at the transfer to the coarse ore stockpile and in the oversize circuit. Water sprays constitute BACT underground because, due to constant movement of the crushing operation, total enclosure or the addition of a wet scrubber would be technically unfeasible. Water sprays constitute BACT at these above ground sources because another large structure to enclose the coarse ore stockpile and/or the oversize circuit would be required to enclose these sources or to route their particulate emissions to a scrubber which would be economically unfeasible for these operations. A wet scrubber (95% control) is proposed to control emissions from the apron feeders and transfer to the SAG Mill; this control device is considered BACT since an additional large structure would be required to enclose these sources, which would be economically unfeasible. The transfer and loading of concentrate is conducted within the mill building; this enclosure (99% control) represents BACT for concentrate transfer activities.

Fugitive emissions from the movement of mobile sources in the underground mine will be negligible due to the high moisture content of traveled surfaces underground. A sprinkler system will operate at the tailings impoundment when needed, to apply water to the portion of tailings not submerged. This control method is estimated to reduce the potential for particulate emissions, which are anticipated to be negligible considering low measured wind speeds at the site, and is considered BACT for this potential fugitive dust source due to the large surface area to be controlled. In addition, Forest Service Road 278 between Montana Highway 2 and the mine site, the primary access route to the mine and where the vast majority of traffic will occur, will be chip sealed, which is anticipated to reduce emissions to near the levels of paved roads.

An air re-circulation/water mister/de-mister system will be installed at the mine upon full production (approximately year 4). This system will re-circulate 300,000 cfm of air for the underground mine. Although an exact emission control efficiency is not known, as each system is custom built by mine site, the mister is estimated to be able to remove nearly 100% of particulate grater than 5 microns in size as well as up to 90% of water soluble pollutants such as NO_x and SO_x. The demister system will then remove the water along with the entrained and dissolved pollutants before the air is re-introduced to the mine. Because of the uncertainty in the control efficiency, no reduction in emissions due to this system was assumed. However, once the system is installed, emissions from the mine portals will be reduced significantly.

3.5 Summary of Emissions

A summary of stationary source emissions can be found in MDEQ permit application forms included with this application as Appendix A. Detailed emissions summaries, and an overall summary of emissions from sources listed under Sections 3.1, 3.2, and 3.3, can be found in the emission calculation sheets included as Appendix C.

4.0 AMBIENT ANALYSIS

As a condition of permit issuance, under ARM 17.8.749(3) the Montanore Mine is required to demonstrate that operation of the facility will not cause or contribute to a violation of any Montana or national ambient air quality standard. To make this demonstration, emissions of the criteria pollutants NO_x, SO_2, PM_{10}, $PM_{2.5}$, and lead were modeled using ISCST3. CO is not analyzed, based on MDEQ guidance. Emissions of VOC were not modeled for this analysis but levels emitted from the Montanore Mine are not expected to cause or contribute to exceedances of the ozone standard. All modeling methodologies follow the requirements outlined in Montana modeling guidance (MDEQ 2002) and are discussed in detail in the Protocol (TRC 2005a), included as Appendix B of this application document. A Montana modeling checklist has been completed for MDEQ review and is included as Appendix F. Electronic modeling files for all analyses performed are contained on CD-ROM in Appendix G.

The remainder of this section presents data not previously included in the Protocol and details on methodologies and parameters revised subsequent to MDEQ comments received on the Protocol.

4.1 Model Settings and Input

4.1.1 MSGPRO

The MSGPRO setting is utilized in the ISCST3 model to allow modeling with the Ramsey on-site meteorological data set, which has missing hourly data. The setting allows ISCST3 to calculate short-term averaging periods for days that contain missing hours, by compiling a daily average based only on valid (non-missing) meteorological hours. Section 3.2.2 of the ISC Users Guide, Volume I documents the MSGPRO setting:

"The missing data processing routines, that are included in the ISC Short Term model as a non-regulatory option, allow the model to handle missing meteorological data in the processing of short term averages. With this option selected, the model treats missing meteorological data in the same way as the calms processing routine, i.e., it sets the concentration (or deposition) values to zero for that hour, and calculates the short-term averages according to EPA's calms policy... If missing data are encountered without the missing data processing option, then the model will continue to read through and check the meteorological data, but will not perform any dispersion calculations."

4.1.2 Meteorological Data

Several hours of the Ramsey Creek meteorological data, initially submitted with the Protocol (TRC 2005a) for review by MDEQ, were found to contain errors and required correction. The wind speed, wind direction, and temperature data were in the incorrect columns for 15 hours: August 12, hours 23 and 24, and August 13, hours 1, 2, and 4 - 14. This error occurred during the data processing of the raw meteorological data set into the processed data set. The raw data file reports the wind speed data for these hours as missing and all other parameters as valid. The processed data set was corrected and the corrected data set was utilized in all ISCST3 model runs and is included in Appendix G.

4.1.3 Model Receptors

Model receptors were analyzed as described in the Protocol (TRC 2005a) with the following exceptions. Additional discrete receptors were placed at prominent terrain features located between 6-10 kilometers from the mine portals, outside of the large-scale 500-meter Cartesian grid proposed in the Protocol. A discrete receptor was also placed at the Libby Courthouse Annex $PM_{2.5}$ monitoring site.

Terrain elevations for these receptors were derived using 7.5-minute DEM data, as discussed in the Protocol. Figure 4.1 provides a graphic representation of 7.5-minute DEM data used.

4.2 Modeled Emission Sources

Emission rates from production, calculated in Section 3.0, were modeled in the ISCST3 analysis. All emission sources planned at the mine were modeled at potential emission rates. For modeling purposes, emission rates utilized were representative of the averaging period modeled. For example, annual emission rates were used to model annual averaging periods, maximum daily emission rates were used to model 24-hour averaging periods, and maximum hourly emission rates were used to derive concentrations for 3-hour and 1-hour averaging periods.

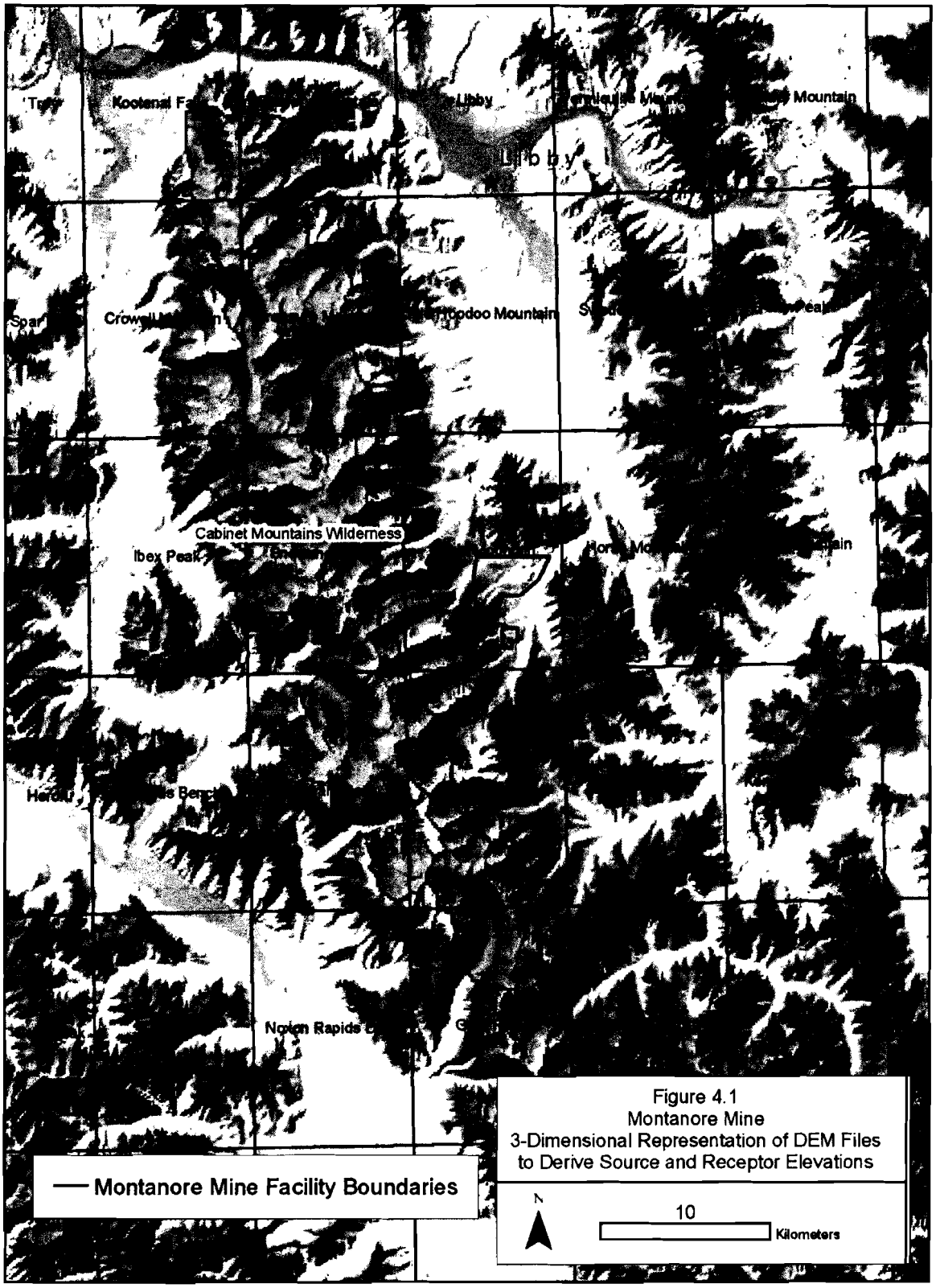

Figure 4.1 DEM File Representation

Table 4.1 presents all modeled source parameters and modeled emission rates used in this analysis. For greater detail in the derivation of modeled emission rates please refer to the final page of Appendix C, Air Emissions Inventory. A discussion of source idealization and modeled parameter development is provided in the following subsections.

4.2.1 Diesel Generator

Emission rates for the operation of an emergency diesel generator to be located at the Ramsey mill site are provided in Table 4.1. Stack data were provided by the specified manufacturer. Two generators (one primary, one standby) will be installed and will operate for a maximum total of 4 hours per quarter in the event of failure of primary and secondary line power sources. Maximum hourly emissions were modeled for 1-hour and 3-hour averaging periods, and 4 hours of maximum hourly operation are modeled for 24-hour averaging periods. Annual average emissions are based on 16 hours per year operation and were modeled for annual averaging periods.

The effects of building downwash on the generator stack were accounted for in ISCST3. The mill building is the only building of significant size and height to be located at the mill site; therefore, the mill building was the focus of this analysis. The mill building has some variance in height on multiple tiers; however, for simplicity and conservatism the entire building was modeled at 21.03, the height of the tallest tier, at a base elevation of 1328 meters. The UTM locations of each building corner are presented below:

Corner	(mE)	(mN)
1.	603857.8	5329591
2.	603917.8	5329558
3.	603920.3	5329562
4.	603935.3	5329554
5.	603977.0	5329629
6.	603927.6	5329657
7.	603911.8	5329628
8.	603886.2	5329642

Table 4.1
Modeled Source Parameters and Emission Rates

Modeled Source ID	Emission Unit No	Source Description	Source Type	Location (UTM)		Elevation	Hs	T or ΔT	Vs or ΔZ	Ds	Emission Rates									Basis
											NO_x		PM_{10}		$PM_{2.5}$		SO_2			
				Easting	Northing	(m)	(m)	(K) or (m)	(m/s) or (m)	(m)	1-hr	Annual	24-hr	Annual	24-hr.	Annual	1,3-hr	24-hr.	Annual	
RAMPORT	1.1-1.5	Ramsey Portal	Point	603962.7	5329301.3	1341.0	15.30	294.0	3.85	8.84	1.46	1.4145	0.1046	0.1005	0.0973	0.0934	0.0174	0.0174	0.0173	500,000 cfm. vertical release.
LIBPORT	1.1-1.5	Libby Portal	Point	605981.0	5328108.0	1233.0	3.00	294.0	3.14	6.19	0.59	0.5666	0.0419	0.0402	0.0390	0.0374	0.0070	0.0070	0.0069	Horizontal release, 18'x18' portal
MSUREQP1	2.1-2.11, 5.1, 6.1	Mill Area Sources and Surface Mobile Equipment	Area	603779.0	5329448.0	1328.0	3.00	150.0	150.00	--	4.631E-06	4.631E-06	1.505E-06	1.46E-06	5.810E-07	5.810E-07	1.063E-06	1.063E-06	1.063E-06	Emissions based on manufacturer's data, AP-42, and sulfur balances 4 sources equally distributed over mill area, 4 equal 150m x 150m area sources, release height equal to 3m. Includes portion of mobile surface equipment operating in mill area and mill process sources.
MSUREQP2		Mill Area Sources and Surface Mobile Equipment	Area	603859.0	5329601.0	1328.0	3.00	150.0	150.00	--	4.631E-06	4.631E-06	1.505E-06	1.46E-06	5.810E-07	5.810E-07	1.063E-06	1.063E-06	1.063E-06	
MSUREQP3		Mill Area Sources and Surface Mobile Equipment	Area	604011.0	5329733.0	1328.0	3.00	150.0	150.00	--	4.631E-06	4.631E-06	1.505E-06	1.46E-06	5.810E-07	5.810E-07	1.063E-06	1.063E-06	1.063E-06	
MSUREQP4		Mill Area Sources and Surface Mobile Equipment	Area	604164.0	5329809.0	1328.0	3.00	150.0	150.00	--	4.631E-06	4.631E-06	1.505E-06	1.46E-06	5.810E-07	5.810E-07	1.063E-06	1.063E-06	1.063E-06	
TAREA1WE/ TAREA1MS/ TAREA1	5.1	Tailings Dam Mobile Surface Equipment	Area	607108.7	5336185.0	1097.3	3.00	770.9	770.90	--	2.014E-07	2.014E-07	5.538E-09	5.538E-09	5.538E-09	5.538E-09	3.573E-08	3.573E-08	3.573E-08	Emissions based on manufacturer's data, AP-42, and

Modeled Source ID	Emission Unit No.	Source Description	Source Type	Location (UTM)		Elevation	Hs	T or ΔY	Vs or ΔZ	Ds	Emission Rates									Basis
											NO_x		PM_{10}		$PM_{2.5}$		SO_2			
				Easting	Northing	(m)	(m)	(K) or (m)	(m/s) or (m)	(m)	1-hr.	Annual	24-hr.	Annual	24-hr.	Annual	1,3-hr	24-hr.	Annual	
TAREA2WE/ TAREA2MS/ TAREA2		Tailings Dam Mobile Surface Equipment	Area	607975.7	5336187.0	1097.3	3.00	770.9	770.90	--	2.014E-07	2.014E-07	5.538E-09	5.538E-09	5.538E-09	5.538E-09	3.573E-08	3.573E-08	3.573E-08	sulfur balances. 2 area sources distributed over tailings area, each 770.9m x 770.9m, release height equal to 3m for mobile equipment Includes portion of mobile surface equipment operating at the tailings area
LAD	5.1	Mobile Surface Equipment at LAD	Area	606869.0	5331613.3	1219.0	3.00	250.0	250.00	--	2.585E-06	2.585E-06	6.590E-08	6.590E-08	6.590E-08	6.590E-08	4.166E-07	4.166E-07	4.166E-07	Emissions based on manufacturer's data, AP-42, and sulfur balances 250m x 250m area source, release height equal to 3m Includes portion of mobile surface equipment operating at the LAD area
LIBLOADR	5.1	Loader at Libby Portal Area	Area	605985.5	5328100.5	1233.0	3.00	15.0	15.00	--	4.020E-04	4.020E-04	1.517E-05	1.517E-05	1.517E-05	1.517E-05	1.005E-04	1.005E-04	1.005E-04	Emissions based on manufacturer's data, AP-42, and sulfur balances 15m x 15m area source, release height equal to 3m Includes a loader operating at the Libby

Modeled Source ID	Emission Unit No.	Source Description	Source Type	Location (UTM)		Elevation	Hs	T or ΔY	Vs or ΔZ	Ds	Emission Rates									Basis
											NO_x		PM_{10}		$PM_{2.5}$		SO_2			
				Easting	Northing	(m)	(m)	(K) or (m)	(m/s) or (m)	(m)	1-hr.	Annual	24-hr.	Annual	24-hr	Annual	1,3-hr	24-hr.	Annual	
																				Portal area
EMRGEN	2.12	Emergency Generator	Point	603805.0	5329600.0	1328.0	2.74	669.3	76.46	0.27	2.8835	0.0053	0.0068	0.0001	0.0068	0.0001	0.0734	0.0122	0.0001	Emissions and stack parameters based on manufacturer's data.

4.2.2 Portals

All underground emissions from the Montanore Mine will exit to the atmosphere through the Ramsey and Libby portals. Due to the large volume of air required to ventilate the mine, all emissions, regardless of release location underground, are assumed to be well mixed with the ventilation air. Total exhaust air from the mine will be 700,000 cfm based on ventilation design. 500,000 cfm will exhaust through the Ramsey portal, while the remaining 200,000 cfm will exhaust through the Libby portal. Therefore, with the assumption the emissions are well mixed with the air, approximately 71% of underground emissions will exhaust through the Ramsey portal and 29% will exhaust through the Libby portal. Underground sources contributing to the portal exhaust emissions are blasting-gaseous and particulate, propane heaters, primary crushers, coarse ore conveyor transfers, and underground mobile sources.

Release characteristics for the Libby portal were revised from those presented in the Protocol. Libby portal exit velocity is calculated to be equivalent to the 200,000 cfm volume exhaust rate from the portal, based on the equivalent diameter of the portal exit area.

Calculated criteria pollutant emissions from underground sources were assumed to be subject to some level of deposition en route to the mine portals. Deposition in the mine was calculated using the Van derHoven equations discussed in "Meteorology and Atomic Energy" (Slade, 1968). The equations were solved iteratively or from figures presented in Slade, 1968 as a function of stability class, wind speed, and deposition velocity. Deposition velocities were obtained from Table 12.5 of "Atmospheric Science and Power Production" (Sehmel, 1984). An assumption was made that the ventilation velocity in the mine would be 1.0 m/s and there would be limited vertical air-flow since airflow in the mine is confined to the portals. Therefore an atmospheric stability of "F" was justified.

The majority of underground emissions at the Montanore mine will occur an average of 19,000 ft from the exhaust portal. Using these parameters for the graph on "Meteorology and Atomic Energy" Figure 5.5 (Slade, 1968), a source depletion fraction was obtained. Using Equation 5.49 (Slade, 1968) to adjust for pollutant specific deposition velocity, an escape fraction for each

pollutant was obtained. Based on the calculation method described above, it was found that approximately 65% of the NO_x, 20% of the SO_2, and 4% of the particulate matter greater than 2.5 microns in size would escape the mine portals. 100% of CO and particulate matter less than 2.5 microns were conservatively assumed to escape. The pertinent sections of "Meteorology and Atomic Energy" (Slade, 1968) and "Atmospheric Science and Power Production" (Sehmel, 1952) are included in this application as Appendix E.

4.2.3 Mill Sources

Emissions from the mill area were modeled using 4 equally sized area sources spread over and approximating the size of the mill area. Emission sources included in the area sources are the ore handling operations leading from the coarse ore stockpile to the mill, the oversize ore crushing/screening train, the laboratory crusher and the portion of the surface mobile equipment expected to operate in the mill area.

4.2.4 LAD

One area source was modeled at the LAD area of the mine. This source represents and contains emissions from surface mobile equipment expected to operate in the LAD area.

4.2.5 Tailings Impoundment

Two equal sized area sources were used to approximate the area and size of the tailings impoundment. For PM_{10}, $PM_{2.5}$ and HAP model runs, two sets of identical area sources were modeled; one set representing emissions from the tailings impoundment wind erosion (TAREA1WE and TAREA2WE) (which were found to be negligible) and one set representing emissions from surface mobile equipment expected to operate at the tailings impoundment (TAREA1MS and TAREA2MS). For NO_x and SO_2 runs, one set of area sources was used (TAREA1 and TAREA2) since these pollutants consisted of only mobile sources.

4.3 NAAQS and MAAQS Analysis

Model results are reported and compared to applicable ambient standards in the following sections. Modeled concentrations are followed by concentration isopleths for each pollutant and averaging period, which illustrate the concentration gradient and location of concentration maxima. Ambient background concentrations as established in the Montanore Plan of Study document (TRC 2005c) and approved by MDEQ (MDEQ 2005c) are shown in Table 4.2, and are added to modeled concentrations from the Montanore Mine to obtain total concentrations for comparison to NAAQS and MAAQS. Annual NO_x concentrations were adjusted using the Ambient Ratio Method (ARM). Hourly NO_x concentrations were adjusted using the Ozone Limiting Method (OLM) as described in the Air Quality Modeling Protocol (TRC 2005a) attached as Appendix B. The ozone ambient standard of 196 $\mu g/m^3$ was conservatively assumed to be ambient background for the OLM calculation. Electronic copies of all model input and output files and supporting data are provided in Appendix G.

Model results for all analyzed pollutants demonstrate compliance with NAAQS and MAAQS, as shown in Table 4.3. All maximum concentrations occurred within the 100-meter receptor grid; therefore, no hotspot receptors were modeled. Maximum short-term concentrations occurred predominantly during periods of calm winds during the fall and winter seasons. The following figures illustrate concentration gradient and location of maximum impact:

- Figure 4.2 - Annual NO_2
- Figure 4.3 - 1-hour NO_2
- Figure 4.4 - Annual SO_2
- Figure 4.5 - 24-hour SO_2
- Figure 4.6 - 3-hour SO_2
- Figure 4.7 - 1-hour SO_2
- Figure 4.8 - Annual PM_{10}
- Figure 4.9 - 24-hour PM_{10}
- Figure 4.10 - Annual $PM_{2.5}$
- Figure 4.11 - 24-hour $PM_{2.5}$

Table 4.2
Ambient Background Concentrations

Pollutant	Averaging Period	Background Concentration ($\mu g/m^3$)	Data Source
PM_{10}	Annual	14	1988-1989 Montanore Mine
	24-Hour	35	1988-1989 Montanore Mine
$PM_{2.5}$	Annual	3.5	Cabinet Mtns Wilderness IMPROVE
	24-Hour	10.4	Cabinet Mtns Wilderness IMPROVE
NO_2	Annual	6	MDEQ
	1-Hour	75	MDEQ
CO	8-Hour	1150	MDEQ
	1-Hour	1725	MDEQ
SO_2	Annual	3	MDEQ
	24-Hour	11	MDEQ
	3-Hour	26	MDEQ
	1-Hour	35	MDEQ
Lead	Annual	0.006	1988-1989 Montanore Mine

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Table 4.3
Maximum Modeled Concentrations Compared to MAAQS and NAAQS

Pollutant	Aver-aging Period	Receptor X(m)	Receptor Y(m)	Receptor Location	Maximum Modeled Concentration (mg/m^3)	Pollutant Background (mg/m^3)	Total Concentration (Modeled + Bkgnd) (mg/m^3)	NO_x to NO_2 Conversion: Concentration using ARM x 0.75	NO_x to NO_2 Conversion: Concentration using ARM plus NO_2 Background (mg/m^3)	NO_x to NO_2 Conversion: Max 1-hr O_3 bkgnd (mg/m^3)	NO_x to NO_2 Conversion: Total Concentration using OLM plus NO_2 Background (mg/m^3)	MAAQS (mg/m^3)	NAAQS (mg/m^3)	% of MAAQS	% of NAAQS
NO_x	Annual	604152	5330147	N Side of Mill Area Boundary	17 97	6		13 48	19 48			94 00	100 00	20 72	19 48
	1-Hour [1]	603661	5329738	NW Side of Mill Area Boundary	1696 75	75				196 00	432 51	564 00	--	76 69	--
SO_2	Annual	604298	5330179	NE Side of Mill Area Boundary	3.59	3	6 59					52.00	80.00	12 67	8 24
	24-Hour [1]	604438	5330095	NE Side of Mill Area Boundary	18.25	11	29.25					262 00	364 00	11 16	8 04
	3-Hour [1]	603732	5329809	N Side of Mill Area Boundary	50.95	26	76 95					--	1300 00	--	5 92
	1-Hour [1]	606089	5327852	SW Side of Libby Portal Boundary	101 39	35	136.39					1300 00	--	10 49	--
PM_{10}	Annual	604298	5330179	NE Side of Mill Area Boundary	5.03	14	19.03					50 00	50 00	38 06	38 06
	24-Hour [1]	604103	5330137	NE Side of Mill Area Boundary	26 37	35	61.37					150 00	150 00	40 91	40 91
$PM_{2.5}$	Annual	604298	5330179	NE Side of Mill Area Boundary	2 06	3.5	5 56					--	15 00	--	37 07
	24-Hour [1]	603732	5329809	NW Side of Mill Area Boundary	12.27	10 4	22.67					--	65 00	--	34 88
Lead	Monthly [2]	603803	5329879	N Side of Mill Area Boundary	3.7E-04	NA	3.7E-04					1 5	1 5	0 02%	0 02%

[1] High 2nd high values
[2] NAAQS is quarterly standadrd, MAAQS is both monthly and quarterly standard.

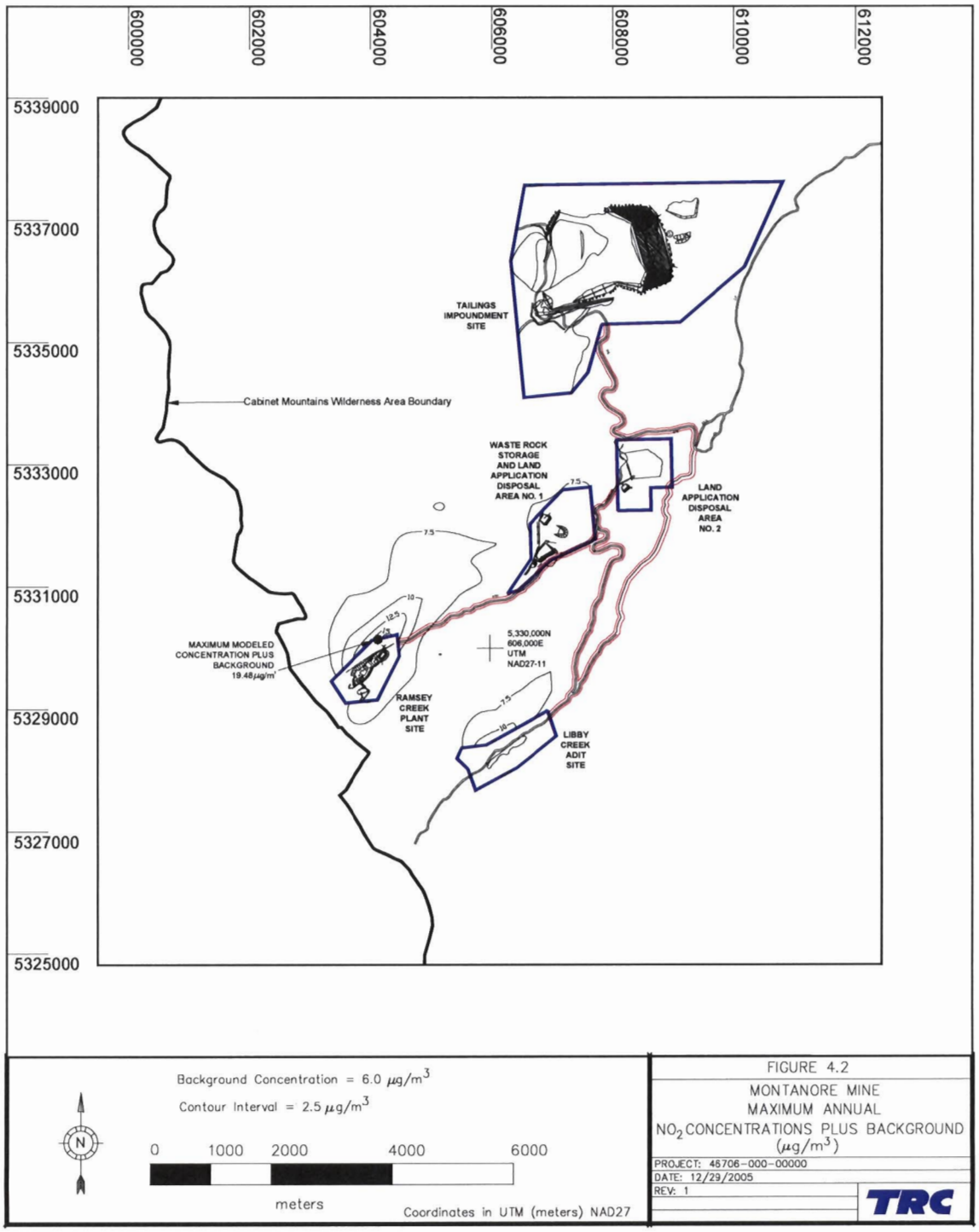

Figure 4.2 Montanore Mine Project Maximum Annual NO_2 Concentration Plus Background ($\mu g/m^3$)

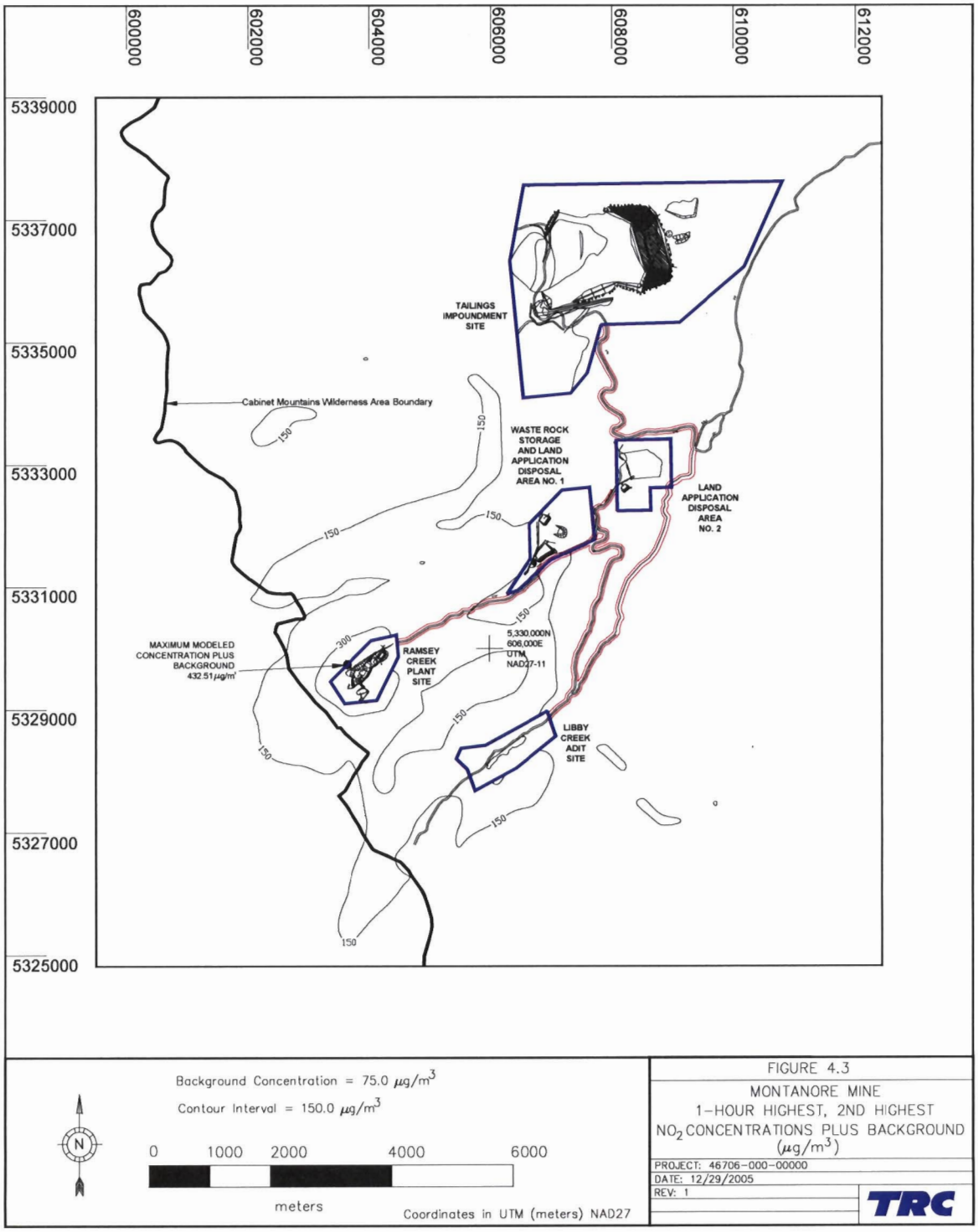

Figure 4.3 Montanore Mine Project 1-Hour Highest, 2nd Highest NO_2 Concentration Plus Background (μg/m³)

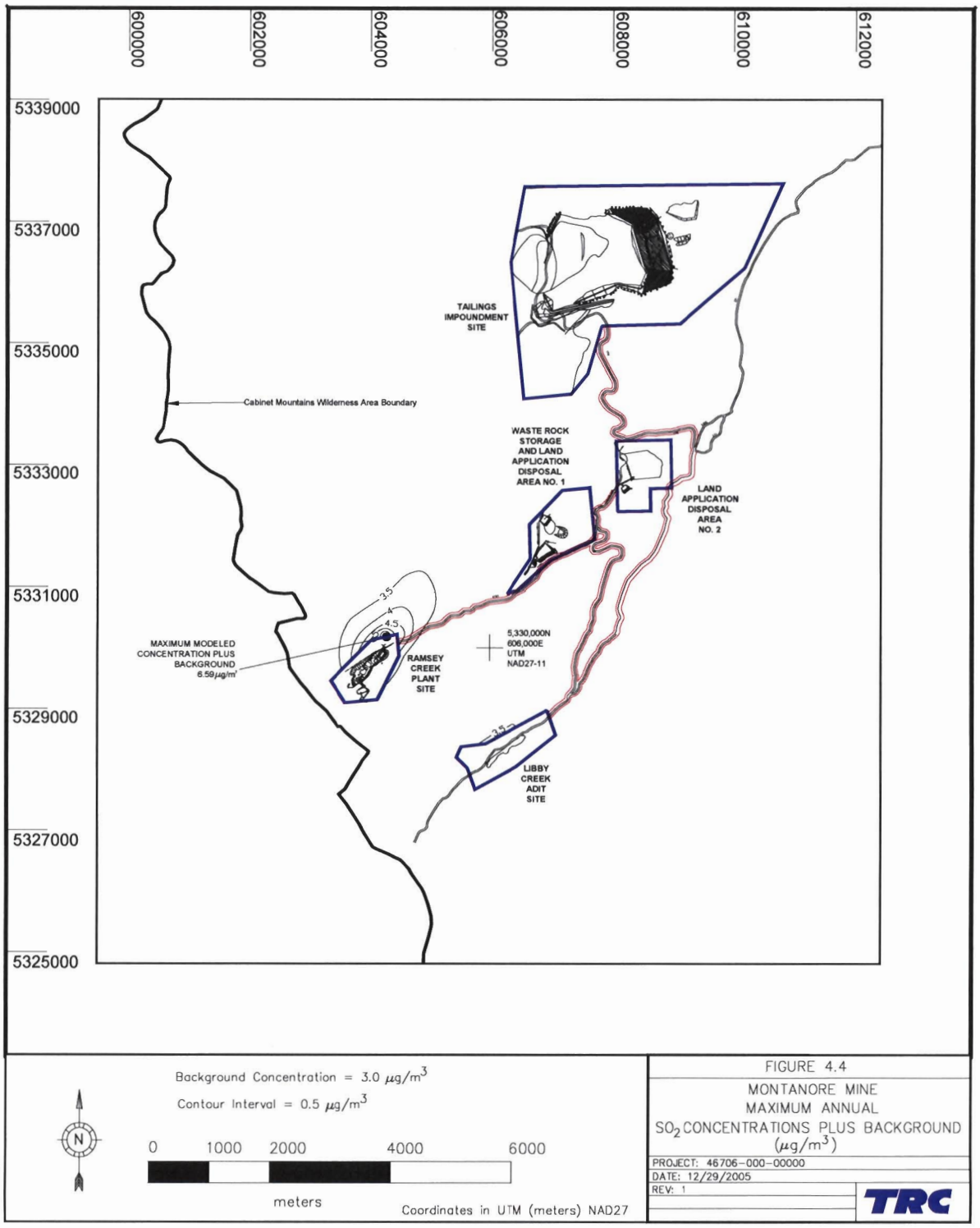

Figure 4.4 Montanore Mine Project Maximum Annual SO_2 Concentration Plus Background ($\mu g/m^3$)

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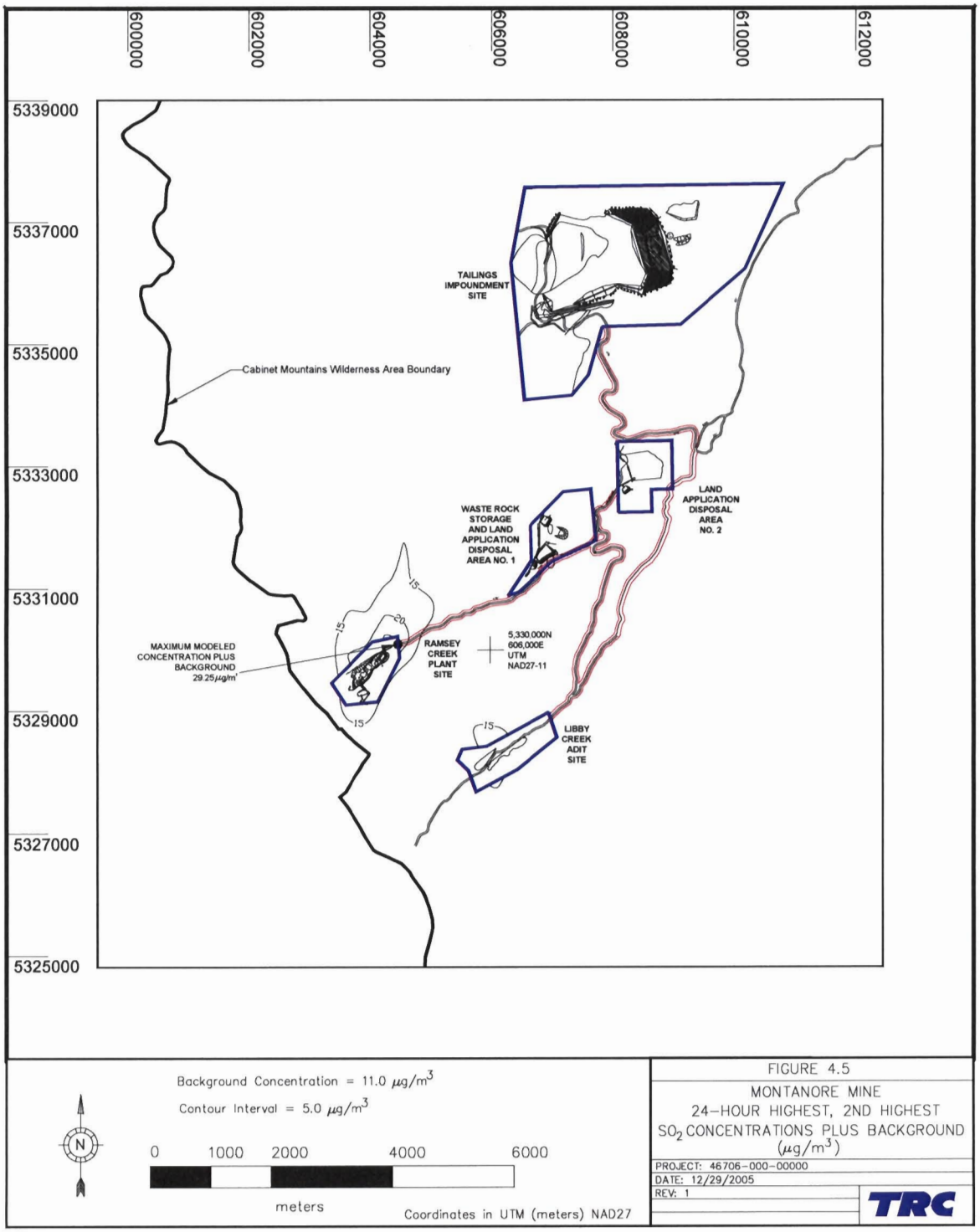

Figure 4.5 Montanore Mine Project 24-Hour Highest, 2nd Highest SO_2 Concentration Plus Background ($\mu g/m^3$)

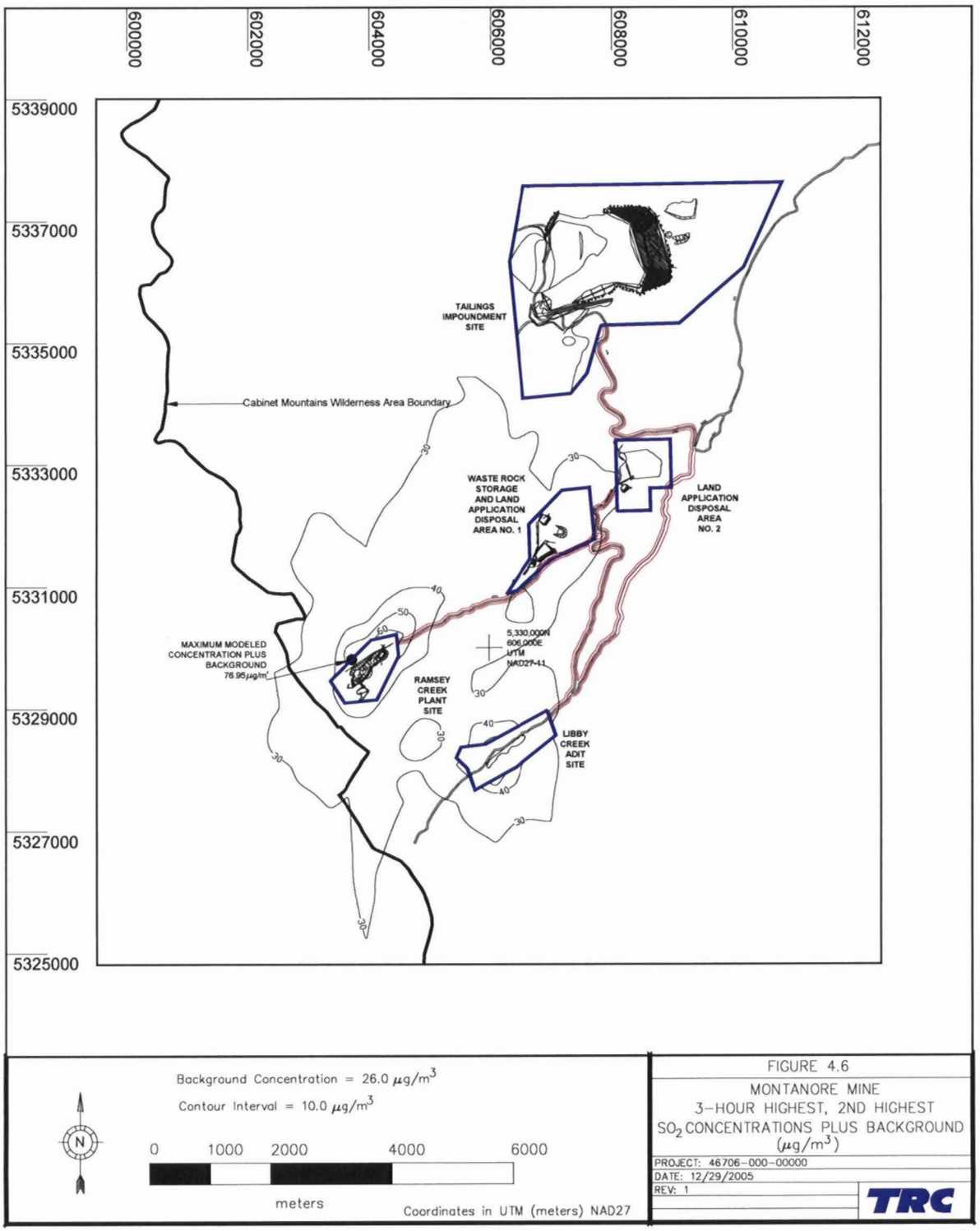

Figure 4.6 Montanore Mine Project 3-Hour Highest, 2nd Highest SO_2 Concentration Plus Background (µg/m³)

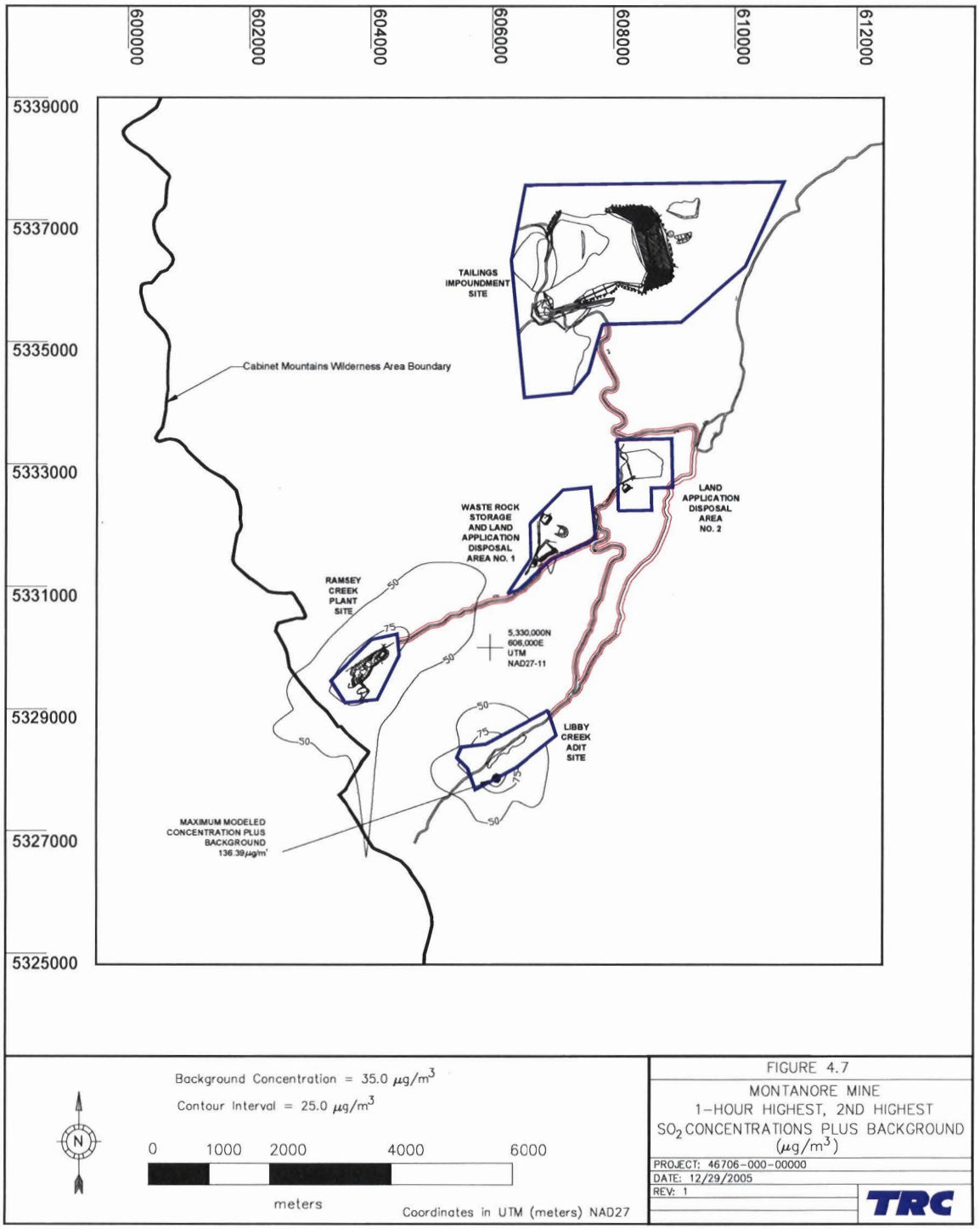

Figure 4.7 Montanore Mine Project 1-Hour Highest, 2nd Highest SO_2 Concentration Plus Background (µg/m³)

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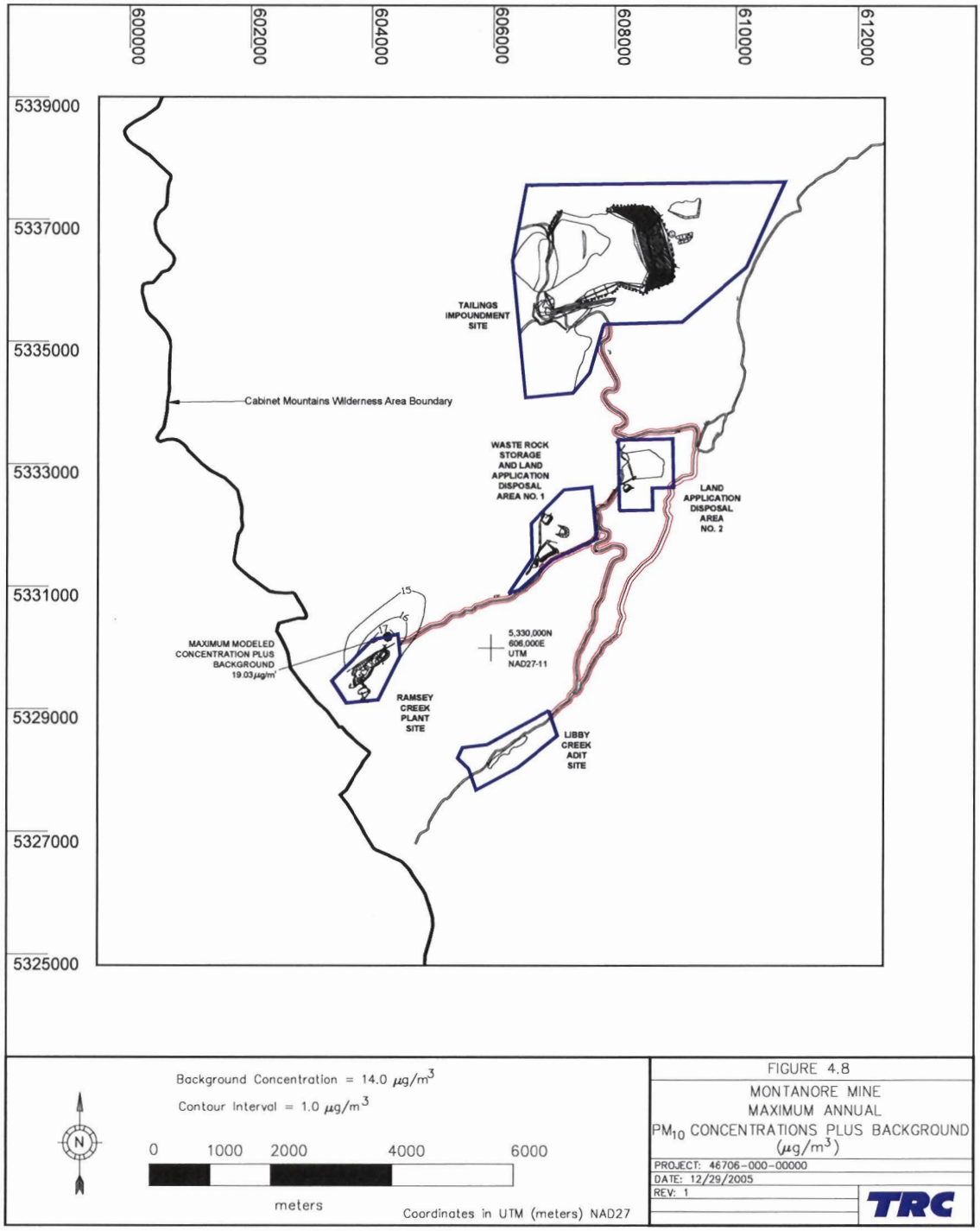

Figure 4.8 Montanore Mine Project Maximum Annual PM10 Concentration Plus Background (µg/m3)

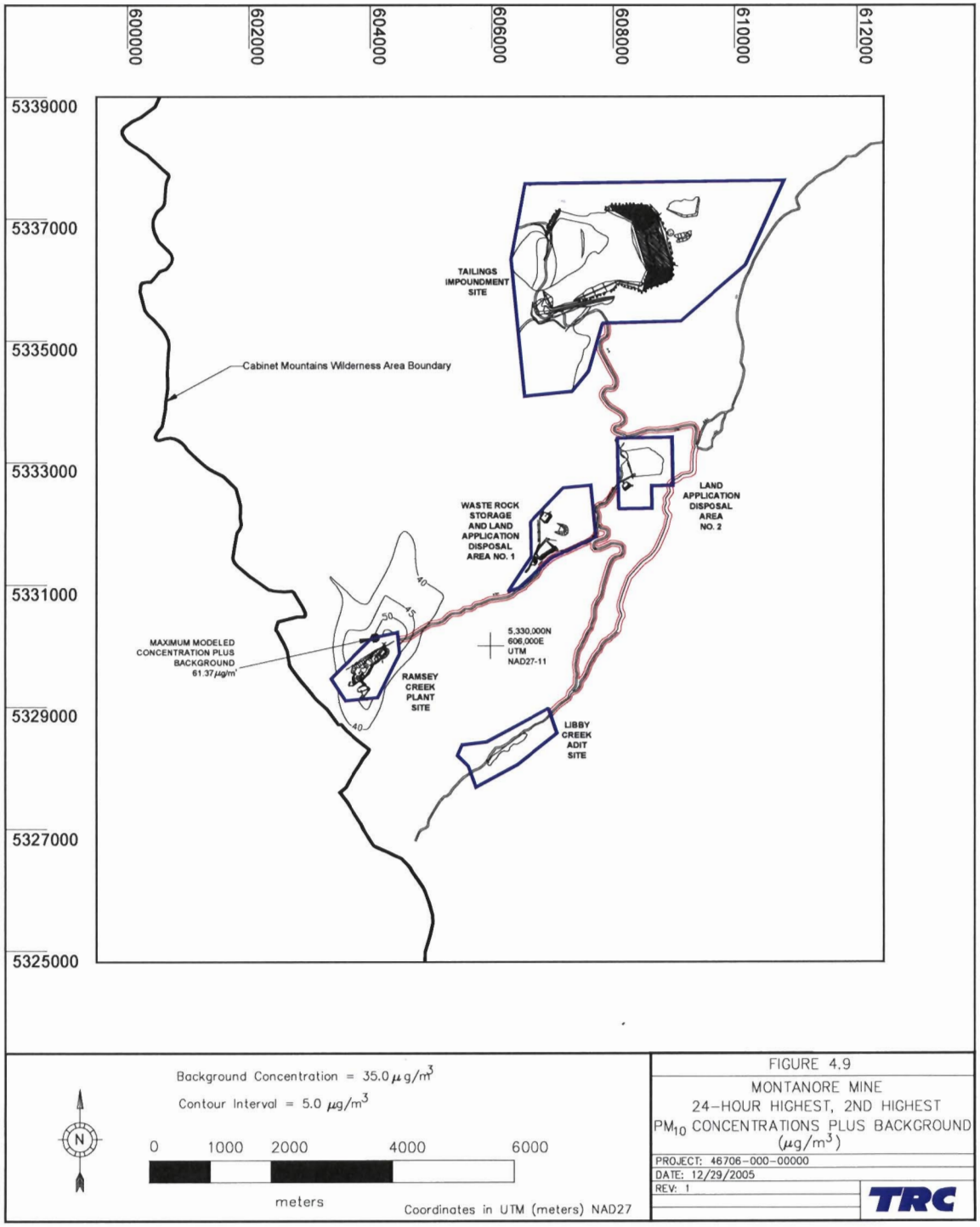

Figure 4.9 Montanore Mine Project 24-Hour Highest, 2nd Highest PM10 Concentration Plus Background (µg/m3)

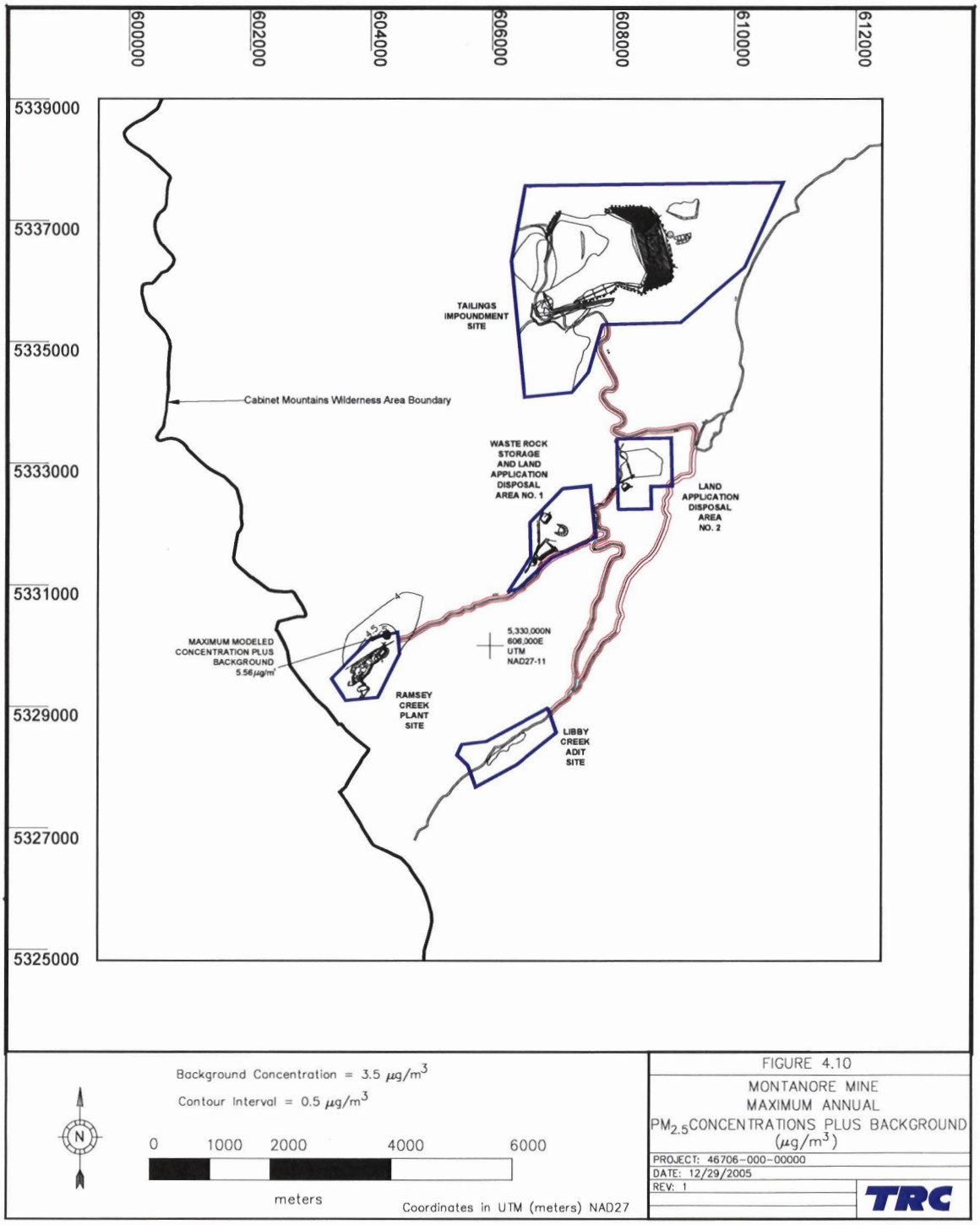

Figure 4.10 Montanore Mine Project Maximum Annual $PM_{2.5}$ Concentration Plus Background ($\mu g/m^3$)

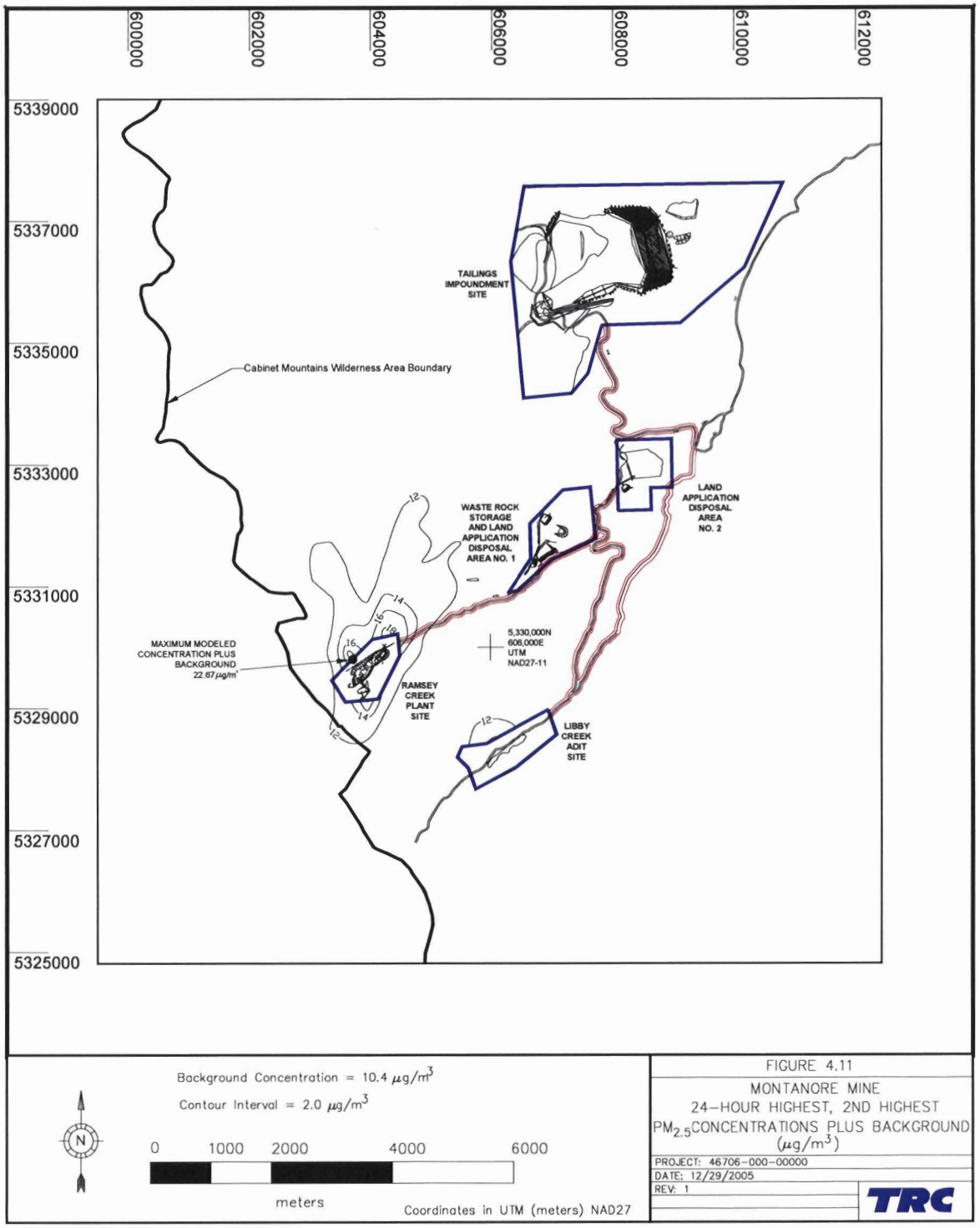

Figure 4.11 Montanore Mine Project 24-Hour Highest, 2nd Highest $PM_{2.5}$ Concentration Plus Background ($\mu g/m^3$)

5.0 OTHER AIR QUALITY DEMONSTRATIONS

In addition to demonstrating compliance with ambient air quality standards, there are a number of other air quality demonstrations required or requested by MDEQ. These include compliance with New Source Performance Standards (NSPS) and Good Engineering Practice (GEP) stack height limitations, restrictions on industrial processes and fuel burning equipment, and limitations on open burning. At the request of MDEQ, several additional modeling demonstrations not required under ARM 17.8 are also performed, including an analysis of impacts to the nearby PSD Class I Area, assessment of human health risk from HAP emissions, assessment of impacts to Libby particulate nonattainment areas, determination of potential effects of terrain downwash, and potential ambient impacts from construction activities. These subjects are discussed in greater detail below.

5.1 New Source Performance Standards

The Montanore Mine is subject to 40 CFR Part 60, Subpart LL, "Standards of Performance for Metallic Mineral Processing Plants." This subpart limits the emission rate of particulate matter from "affected facilities" at metallic mineral processing plants. Affected facilities are defined as each crusher and screen in open-pit mines; each crusher, screen, bucket elevator, conveyor belt transfer point, thermal dryer, product packaging station, storage bin, enclosed storage area, truck loading station, truck unloading station, railcar loading station, and railcar unloading station at the mill or concentrator. All facilities located underground are exempt from this subpart.

On and after the date on which the performance test required to be conducted by 60.8 is completed, no stack may discharge into the atmosphere any emissions that contain particulate matter in excess of 0.05 grams per dry standard cubic meter. The stacks shall also not exhibit greater than 7% opacity, unless the emissions are discharged from an affected facility using a wet scrubbing device. On or after the sixtieth day of achieving the maximum production rate, but not later than 180 days after initial start-up, no owner or operator shall cause to be discharged into the atmosphere from an affected facility any process fugitive emissions that exhibit greater than 10% opacity.

Water sprays, wet Venturi type scrubbers, and enclosures at the Montanore Mine will control emissions from the affected facilities within the required levels. Mines Management will follow the monitoring, testing, recordkeeping, and reporting requirements of this subpart to show continued compliance with the subpart.

5.2 Good Engineering Practice Stack Height

The stack height for which ambient air quality modeling can take credit is defined as GEP stack height. GEP can be determined by several different methods, but without special demonstrations, the minimum value of GEP stack height is 65 feet. All stacks at the Montanore Mine were modeled using actual stack heights, and no stack heights proposed exceed 65 feet; therefore, the analysis complies with Good Engineering Practice.

5.3 Industrial Processes and Fuel Burning

In accordance with ARM 17.8.304(2), no emissions to the atmosphere from any source will exhibit greater than 20% opacity. This will be obtained with good combustion and blasting practices, as well as controls such as enclosures, water sprays, and wet Venturi type scrubbers.

In accordance with ARM 17.8.308, no emissions of particulate matter will be emitted to the atmosphere from the transfer, production, handling or transportation of any material without reasonable precautions to control airborne particulate. No emissions from any stationary source will exhibit greater than 20% opacity. This will be obtained with good combustion and blasting practices, as well as controls such as enclosures, water sprays, and wet Venturi type scrubbers.

In accordance with ARM 17.8.309, no fuel burning equipment at the site will exceed the emissions limitations as set forth in the table contained in that section. See the emissions inventory attached as Appendix C for source specific emission rates.

In accordance with ARM 17.8.310, no particulate matter will be discharged from any operation, process or activity at the site to the atmosphere that is in excess of the amount allowed by the

table contained within that section. See the emissions inventory attached as Appendix C for source specific emission rates of particulate matter.

All requirements as set forth in ARM 17.8.322 will be met by emissions units at this facility for the combustion of sulfur containing fuel. Emissions will be met by using off-road diesel fuel, which by 2007 will be required to a maximum of 0.05% or 50 ppm sulfur.

5.4 Open Burning

ARM 17.8.601 imposes restrictions on open burning. No open burning is scheduled to take place at the Montanore Mine site. If open burning is in fact needed in the future, Mines Management will follow all applicable requirements.

5.5 Cabinet Mountains Wilderness Area Impact Assessment

A visibility impact assessment, acid deposition impact assessment, and comparison of modeled concentrations to PSD Class I Increments are not explicitly required for minor source preconstruction permits under ARM 17.8.7. However, due to the close proximity (0.25 mi) of the Montanore Mine to the Cabinet Mountains Wilderness Area, a PSD Class I Area, and for reference in the Supplemental Environmental Impact Statement for the Montanore Mine being prepared concurrent to this application, MDEQ has requested that these analyses be completed.

An analysis of concentration impacts at and within the PSD Class I Area boundary was completed, and concentrations compared to PSD Class I Increments which exist for NO_x, SO_2, and PM_{10}. Modeling methodology follows Section 4.0 of this application and the Protocol (TRC 2005a) attached as Appendix B, and utilizes emissions sources identical to the analysis described in Section 4.0. Model receptors with terrain elevations were placed at the Cabinet Mountains Wilderness Class I Area boundary and within the wilderness area. Modeled concentrations were predicted to be less than PSD Class I Increments at all locations at and within the Class I Area boundary. Maximum modeled concentrations are compared to PSD Class I Increments in Table 5.1.

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Table 5.1
Comparison to PSD Class I Increments

Pollutant	Averaging Period	Receptor X(m)	Receptor Y(m)	Receptor Location	Maximum Modeled Concentration (mg/m^3)	ARM NOx to NO2 Conversion x 0.75	Class I Increment (mg/m^3)	% of Class I Increment	# of Occurences Over Increment	Compliance Status
NO_x	Annual	603573	5328675	Class I Boundary SW of Mill Area	1.72	1.29	2.50	51.60	--	In
SO_2	Annual	603573	5328675	Class I Boundary SW of Mill Area	0.18		2.00	9.00	--	In
	24-Hour [1]	603491	5328713	Class I Boundary SW of Mill Area	3.73		5.00	74.60	--	In
	3-Hour [1]	603372	5328874	Class I Boundary SW of Mill Area	12.57		25.00	50.28	--	In
PM_{10}	Annual	603573	5328675	Class I Boundary SW of Mill Area	0.29		4.00	7.25	--	In
	24-Hour [1]	603491	5328713	Class I Boundary SW of Mill Area	5.06		8.00	63.25	--	In

[1] High 2nd high values used.

Potential visibility impacts to the Cabinet Mountains Wilderness Class I Area and acid deposition impacts at sensitive lakes within the wilderness area will be calculated independently from this application and submitted to MDEQ under separate cover. The analyses will be conducted using the methodology set forth in the protocol response letter to MDEQ (TRC 2005b), and concurred with in (MDEQ 2005b).

5.6 Nonattainment Area Boundary Impact Assessment

The Libby, MT area is classified as nonattainment for PM_{10}. A $PM_{2.5}$ nonattainment designation for the Libby, MT area is pending. The extents of the land area designated as nonattainment for each of these pollutants are shown in Figure 5.1. The Montanore Mine underground access and surface mill/surface operations are not within either nonattainment area, and the tailings impoundment, the northernmost mine activity, is located approximately 1.5 miles south of the southern extent of the $PM_{2.5}$ nonattainment boundary and 8.9 miles south of the southern extent of the PM_{10} nonattainment boundary. The Montanore Mine's rail loading facility in Libby is located within both nonattainment areas. The loading facility will emit no pollutants to the atmosphere due to the surface moisture of the concentrate and the operational need for the loading activities to be enclosed by a building.

MDEQ requested that an analysis be performed to predict ambient PM_{10} and $PM_{2.5}$ contributions from the Montanore Mine to air quality in these nonattainment areas, including the assessment of sulfate and nitrate contribution to total $PM_{2.5}$ impacts. The CALPUFF model (Version 5.711a) was run in accordance with methodology proposed in (TRC 2005b) and responded to in (MDEQ 2005b). Meteorological data utilized in the CALPUFF model consisted of Ramsey Creek on-site meteorological data processed for the AAQS demonstration, combined with representative regional data to include the extended parameters necessary for CALPUFF and replace missing hours. Concurrent Kalispell, MT SAMSON data and Spokane, WA mixing height data were processed with MPRM using coniferous forest surface characteristics from the MPRM User's Guide. The extended parameters necessary to run CALPUFF, solar radiation and relative humidity, were obtained from the Kalispell/Spokane dataset. In addition, because CALPUFF cannot handle periods of missing data, hourly parameters missing in the Ramsey Creek data were replaced with values from the Kalispell/Spokane dataset.

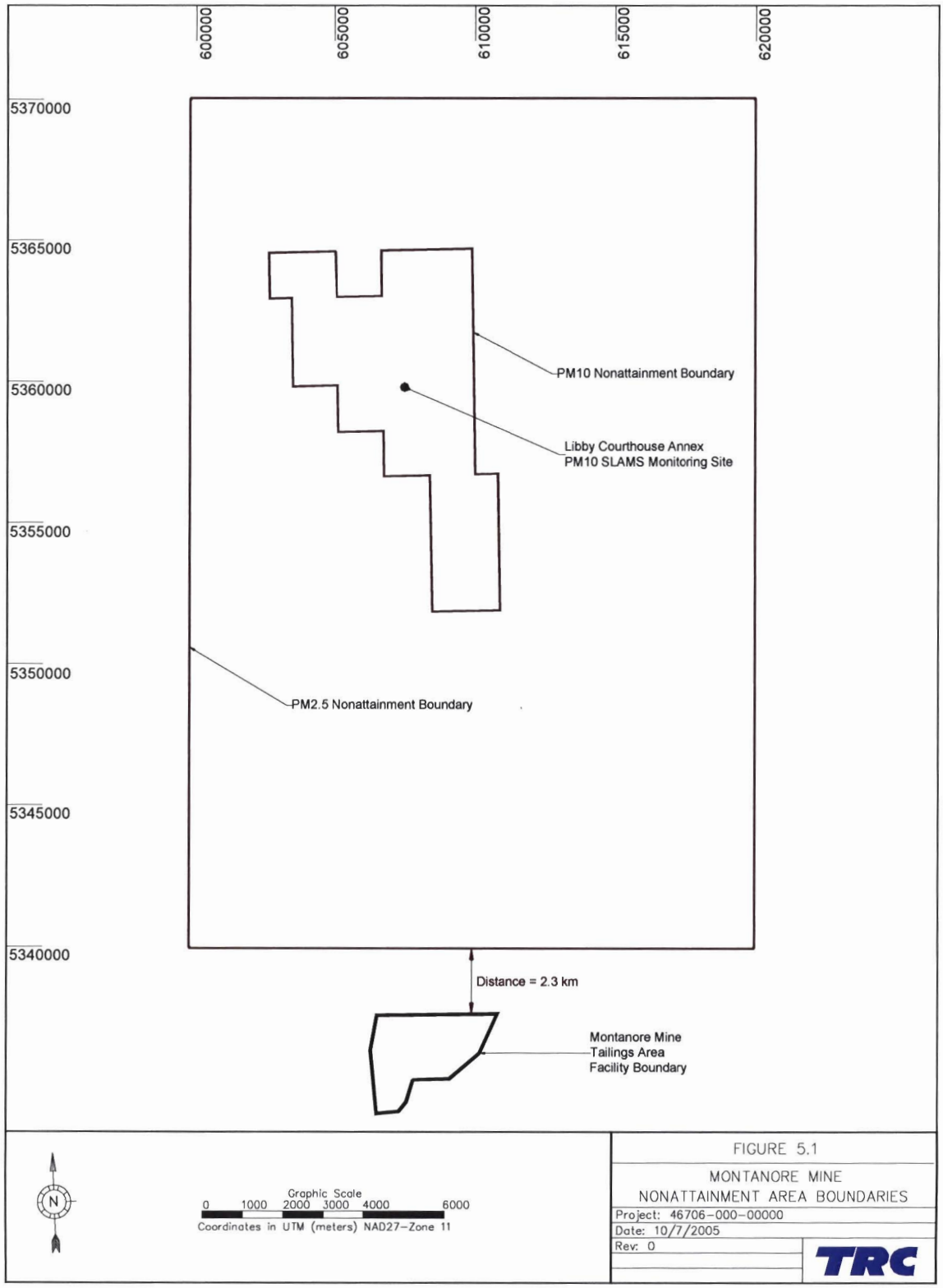

Figure 5.1 Non-Attainment Area Boundaries

Modeled concentrations of PM_{10} and $PM_{2.5}$ from Montanore Mine operations are compared to EPA's proposed PSD Class II significance levels for PM_{10} and, in the absence of a significance level for $PM_{2.5}$, to the equivalent value (2% of AAQS) for $PM_{2.5}$. Modeled concentrations were predicted to be less than these significance levels, indicating that mine operations would not significantly impact PM_{10} and $PM_{2.5}$ concentrations within these nonattainment areas. Table 5.2 summarizes modeled concentrations and significance levels. CALPUFF, POSTUTIL, and CALPOST input and output files are contained on CD-ROM in Appendix G.

Table 5.2
Comparison of Non-Attainment Area Modeled Concentrations to PSD Class II Significance Levels

Non-attainment Area	Pollutant and Averaging Period	Maximum Modeled Concentration ($\mu g/m^3$)	PSD Class II Significance Level [1] ($\mu g/m^3$)
Libby, MT PM_{10}	PM_{10} Annual	0.035	1
	PM_{10} 24-Hour	0.66	5
Libby, MT $PM_{2.5}$	$PM_{2.5}$ Annual	0.086	0.3
	$PM_{2.5}$ 24-Hour	1.04	1.3

1. PM_{10} significance levels proposed. $PM_{2.5}$ significance levels calculated as 2% of $PM_{2.5}$ ambient standard.

5.7 HAP Impact Assessment

Trace metals are present in ore, tailings, and concentrate. During mining, handling, and processing of these materials, emissions of these metals, some of which are identified as HAPs, may occur as a fraction of the particulate emitted from these operations. The Montanore Mine is not explicitly required by ARM 17.8 Sub-Chapter 7 to assess human health risks from HAP emissions. However, a human health risk assessment is performed for the trace metals classified as HAPs to provide a full disclosure of potential HAP impacts.

The analysis predicted concentrations of lead (also a criteria pollutant and analyzed in Section 4.0), arsenic, antimony, cadmium, and chromium. No Montana guidance exists for a risk assessment for this facility type; as a result, concentrations are compared to several risk

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assessment levels. Comparison is made to the risk assessment levels defined for incinerators in ARM 17.8.770 Tables 1 and 2 for carcinogens and non-carcinogens. Comparison is also made to currently established non-carcinogenic inhalation reference concentrations (RfC) obtained from the Integrated Risk Information System (IRIS) database (IRIS 2005). RfCs generally define levels below which no deleterious effects from inhalation of a substance would occur. Also, carcinogenic risk is calculated based on currently established unit risk factors for lifetime exposure as defined in IRIS (IRIS 2005). These comparisons are shown in Table 5.3.

As illustrated in Table 5.3, lead and antimony modeled concentrations are less than MDEQ carcinogenic incinerator risk assessment levels, and arsenic, cadmium, and chromium modeled concentrations are predicted to be above MDEQ carcinogenic incinerator risk assessment levels. Modeled concentrations of arsenic, antimony, cadmium, and lead are below MDEQ non-carcinogenic incinerator risk levels, and the chromium concentration is greater than the MDEQ non-carcinogenic incinerator risk assessment level for that substance.

Chromium is the only substance for which a non-carcinogenic RfC exists, and modeled chromium concentrations are less than the RfC. Carcinogenic unit risk factors exist for arsenic, cadmium, and chromium only, and when modeled concentrations are multiplied by the unit risk factors for these substances, cancer risk for a lifetime of exposure to each substance individually is no greater than 3 in 1,000,000 (arsenic) and is as little as 1 in 10,000,000 (cadmium). Total combined cancer risk from these three substances is determined by summing the cancer risk for all, and is found to be 5 in 1,000,000. These lifetime cancer risks are based on a 70-year lifetime of exposure; the Montanore Mine is proposed to operate only 15 years, therefore, exposure time would be reduced and cancer risk would be proportionately reduced. Predicted lead concentrations are well below the quarterly AAQS as shown in Table 4.3.

Table 5.3
Modeled HAPs Concentrations

Pollutant	Averaging Period	Receptor X(m)	Receptor Y(m)	Receptor Location	Maximum Modeled Concentration (µg/m3)	ARM 17.8.770 Annual Cancer Exposure Level (µg/m3)	ARM 17.8.770 Annual Non-Cancer Chronic Exposure Level (µg/m3)	IRIS Annual Non-Cancer Chronic RfC (µg/m3)	IRIS Lifetime Cancer Risk Factor (per µg/m3)	Lifetime Exposure Cancer Risk
As	Annual	604298	5330179	NE Side of Mill Area Boundary	7.80E-04	2.33E-05	5.00E-03	None	4.30E-03	3E-06
Cd	Annual	604298	5330179	NE Side of Mill Area Boundary	8.00E-05	5.56E-05	3.50E-02	None	1.80E-03	1E-07
Cr	Annual	604298	5330179	NE Side of Mill Area Boundary	1.20E-04	8.33E-06	2.00E-05	0 1	1.20E-02	1E-06
Sb	Annual	604298	5330179	NE Side of Mill Area Boundary	8.00E-05	2.00E-03	2.00E-03	None	None	--
Pb	Monthly	603803	5329879	N Side of Mill Area Boundary	3.70E-04	1.50E-02	1.50E-02	None	None	--
								Total lifetime cancer risk		5E-06

5.8 Terrain-Induced Building Downwash

At MDEQ request, the potential effects of terrain-induced downwash were analyzed. To simulate the downwash that may be present due to the hillside rising sharply near the Ramsey portal, a "building" 20m x 20m with a height of 10m was positioned along the hillside directly adjacent to the cut-bank above where the portal exits the mountainside. The EPA's BPIP program was utilized to provide downwash parameters for input into the ISC model.

Test model runs were completed using both elevated terrain and flat terrain to evaluate the effects of potential terrain downwash on each. All sources and receptors in these test runs were identical to the compliance runs discussed in Section 4.0. Hillside downwash had no effect on maximum concentrations when utilizing elevated terrain; maximum modeled results from all sources and receptors for short-term (1-hr) NO_x with hillside downwash were identical to the results with no hillside downwash. With flat terrain the same result was found; maximum modeled concentrations for short-term (1-hr) NOx with hillside downwash were identical to the results with no hillside downwash. Test runs completed are available from TRC upon request.

5.9 Construction Inventory and Analysis

5.9.1 Construction Emissions

Construction activities will be temporary and will precede full production in year 4. During the first phase of construction, underground construction activities will begin, no major surface construction activities will occur, and one 1-MW diesel electric generator (with one identical co-located unit on standby) will operate continuously at the Libby site for construction support during electric utility installation. The generator will operate until line power becomes available, which is expected to be less than one year from commencement of construction activities. Upon completion of the Libby underground electric transmission line, the 1-MW generator will operate as an emergency backup only, operating a maximum of 4 hours per calendar quarter as during mine production. Underground and surface construction equipment will be owned and operated by private contractors, and any permits required for construction equipment will be the responsibility of those contractors.

Air emissions from diesel generator operation and underground construction activities during the first phase of construction are calculated in Appendix D.

5.9.2 Construction Modeling Analysis

Dispersion modeling was performed for the first phase of construction, the only portion of construction during which a generator would operate continuously, to demonstrate that construction activities would comply with ambient air quality standards. NO_x emissions from one 1-MW generator operating continuously for a full year, and from underground activity equivalent to those exiting the Libby portal during production, were modeled with the ISCST3 model. Modeled emission rates are provided in Appendix D. NO_x was analyzed because that pollutant is emitted in the largest quantity, and because NO_x concentrations in the production compliance modeling were the closest to their respective AAQS. Model settings and input data were identical to those presented in the compliance modeling set forth in Section 4.0 of this application. The maximum hourly NO_x emission rate was modeled year-round, and Libby portal emissions were modeled equal to those included in production modeling.

The maximum-modeled 1-hour NO_2 concentration (adjusted using the OLM and O_3 ambient standard of 196 $\mu g/m^3$) was found to be 367 $\mu g/m^3$ and the maximum annual average NO_2 concentration (adjusted using the ARM) was found to be 47.5 $\mu g/m^3$. Both concentrations are less than the Montana ambient standards of 564 and 94 $\mu g/m^3$, respectively. Model input and output files are included in Appendix G.

6.0 REFERENCES

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TRC, 2005a. Letter to Eric Thunstrom, Montana Department of Environmental Quality from Susan Connell, TRC Environmental Corporation, regarding Mines Management Inc. Montanore Mine Project Minor Source Permit Application Modeling Analysis Protocol, September 22, 2005.

TRC, 2005b. Letter to Eric Thunstrom, Montana Department of Environmental Quality from Susan Connell, TRC Environmental Corporation, regarding Mines Management Inc. Montanore Mine Project Minor Source Permit Application Modeling Analysis Protocol, December 12, 2005.

TRC, 2005c. Letter to Eric Thunstrom, Montana Department of Environmental Quality from Susan Connell, TRC Environmental Corporation, regarding Revised NEPA Plan of Study Mines Management Inc. Montanore Mine, June 20, 2005.

APPENDIX A

MDEQ PERMIT APPLICATION FORMS

Department of Environmental Quality

Air Resources Management Bureau • P.O. Box 200901 • Helena MT 59620-0901 • (406) 444-3490

MONTANA AIR QUALITY PERMIT APPLICATION FOR STATIONARY SOURCES

Montana Department of Environmental Quality
Air Resources Management Bureau
Permitting Section Supervisor
1520 E. Sixth Avenue
P.O. Box 200901
Helena, MT 59620-0901
Phone: (406) 444-3490 FAX (406) 444-1499

For State of Montana Use Only
Permit Application Number _____
Application Fee Paid with Application?
☐ Yes ☐ No Amount Paid _____
AREV Facility # _____ FP ID # _____

Four complete copies of the application, any associated fees, and the affidavit of publication of the attached public notice must be mailed to the above address. Instructions for filling out this form are contained in the Instructions and Suggested Format document available from the Department of Environmental Quality (Department). Some information requested in this application may not be applicable to all facilities. Please contact the Air Resources Management Bureau if you have any questions. Depending on the applicable air quality programs a final permit will be issued within 76 or 91 days of the Department's receipt of a complete application barring any appeals to the Board of Environmental Review (Board).

FACILITY NAME AND ADDRESS (As registered with the Montana Secretary of State)

Mines Management Inc. (an Idaho corporation) Montanore Mine
Facility Name

905 W. Riverside Ave. Suite 311
Mailing Address

Spokane (*City*) WA (*State*) 99201 (*Zip*)

PERMIT TYPE

☒ Air Quality Preconstruction Permit

- ☒ New Facility
- ☐ Modification to Existing Permit _____ *Permit Number*
- ☐ Synthetic Minor (major source using federally enforceable permit conditions to avoid MACT, PSD, NSR, or Title V Operating Permit requirements)

A permit application fee and an affidavit of publication must be submitted to the Department at the above address (for air quality preconstruction permit applications only)

Affidavit of Publication of Public Notice	☐ Attached	☐ Forthcoming
Permit Application Fee	☐ Attached	☐ Forthcoming

☐ Air Quality Operating Permit

- ☐ Initial Air Quality Operating Permit - - New Construction
- ☐ Initial Air Quality Operating Permit - - Existing Source
- ☐ Renewal of Air Quality Operating Permit
- ☐ Modification of Air Quality Operating Permit

Name of DEQ Contact Eric Thunstrom
If you have been dealing with Department of Environmental Quality personnel

The estimated time for the Department to process and act on a correctly completed application form is 60 days. The Department has 30 days to notify an applicant that their application is incomplete. The Department shall make a preliminary determination within 40 days after receiving a complete and filed application. A Department decision must be made within 60 days after receiving a complete application. The Department decision is not final unless 15 days have elapsed from the date of the Department decision and there is no request for a hearing before the Board of Environmental Review. (Different time frames apply if an Environmental Impact Statement is required or if the Major Facility Siting Act is applicable. Provisions also exist in rule for extending the time for issuing a department decision). Please refer to ARM 17.8.706(2), ARM 17.8.720 and 75-2-211 MCA.

§ 1.0 GENERAL FACILITY INFORMATION AND SITE DESCRIPTION

PHYSICAL LOCATION			
Address (if different from mailing address)			
Mailing Address			
City	*State*	*Zip*	
Section (to nearest)	*Township*	*Range*	*County*

Owner's Name Mines Management, Inc. Telephone

Facility Manager' Name Paul Martin Telephone 509-838-6050

Contact Person Eric Klepfer Telephone 509-838-6050

General Nature of Business Silver and Copper Ore Mine and Mill

Standard Industrial Classification Codes(s)

Standard Industrial Classification Description(s)

Total Property Area _____ *Acres* Current Number of Employees

Estimated Capital Expenditure for Proposed Project [1, 2]

Estimated Cost of Air Pollution Control Equipment [1, 2]

Number of Permanent New Employees as a Result of the Proposed Project [2]

Permit numbers and permit type of any previous or existing air quality permits issued to this facility (*need not include air quality permit whose requirement have been superseded).*

Construction/Installation Schedule: [2] _____ *Estimated Starting Date* _____ *Estimated Completion Date*

Duration (temporary source): [2] _____ *Estimated Starting Date* _____ *Estimated Completion Date*

§ 1.1 Narrative Description of the Site and Facility (see Section 2.0 of permit application document)

§ 1.2 Site Map (see Figure 1.1 of permit application document)

§ 1.3 Narrative Project Summary [2] (see Section 2.0 of permit application document)

§ 1.4 Project and Site Information Request. (Complete the questionnaire on pages 11 and 12 of the application) [2]

[1] This information is optional and not required. You may supply an estimate, state a range, or decline to supply this information.
[2] Not required for operating permit applications.

§ 2.0 EMISSION UNIT LISTING

Attach a list of all existing and proposed emission units. For air quality operating permits only, note all insignificant emission units.

EMISSION UNIT LISTING	New Source	Existing Source	Insignificant Yes	Insignificant No
1.1 Blasting – Particulate and Gaseous	☒	☐	☐	☒
1.2 Propane Heaters	☒	☐	☐	☒
1.3 Primary Crushers	☒	☐	☐	☒
1.4 Coarse Ore Conveyor Transfers	☒	☐	☐	☒
2.1 Conveyor to Coarse Ore Stockpile	☒	☐	☐	☒
2.2 Apron Feeders	☒	☐	☐	☒
2.3 Conveyor Discharge to SAG Mill	☒	☐	☐	☒
2.4 Concentrate Transfer	☒	☐	☐	☒
2.5 Concentrate Loading	☒	☐	☐	☒
2.6 Oversize Transfer to Hopper	☒	☐	☐	☒
2.7 Oversize Reclaim Belt Transfer	☒	☐	☐	☒
2.8 Oversize Crusher	☒	☐	☐	☒
2.9 Oversize Screen	☒	☐	☐	☒
2.10 Belt Transfer Back to SAG Mill	☒	☐	☐	☒
2.11 Coarse Ore Stockpile Wind Erosion	☒	☐	☐	☒
2.12 Emergency Generator	☒	☐	☐	☒
3.1 Haul Truck Travel	☒	☐	☐	☒
4.1 Tailings Impoundment Wind Erosion	☒	☐	☐	☒
6.1 Laboratory Crusher	☒	☐	☐	☒
	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 1.1 Blasting – Particulate and Gaseous

§ 3.1.2 Potential Emissions Summary [3]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		0.40	2.31	
SO_2		0.14	0.82	
Pb		2.02E-5		
NOx		1.33	7.57	
VOC				
CO		64.66	369.5	
Other *(specify)*: $PM_{2.5}$		0.02	0.13	
Other *(specify)*: As		8.08E-5		
Other (*specify)*: Sb		8.08E-6		
Other *(specify)*: Cr		1.21E-5		
Other *(specify)*: Cd		8.08E-6		
Other *(specify)*:				

[3] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 1.2 Propane Heaters

§ 3.1.2 Potential Emissions Summary [4]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		0.07	0.92	
SO_2		2.78E-3	3.69E-2	
Pb				
NOx		2.44	32.26	
VOC		0.09	1.15	
CO		0.33	4.38	
Other *(specify)*: $PM_{2.5}$		0.07	0.92	
Other *(specify)*:				
Other *(specify)*:				
Other *(specify)*:				
Other *(specify)*:				
Other *(specify)*:				

[4] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 1.3 Primary Crushers

§ 3.1.2 Potential Emissions Summary [5]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		3.26	18.63	
SO_2				
Pb		1.63E-4		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		0.65	3.73	
Other *(specify)*: As		6.52E-4		
Other *(specify)*: Sb		6.52E-5		
Other *(specify)*: Cr		9.78E-5		
Other *(specify)*: Cd		6.52E-5		
Other *(specify)*:				

[5] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 1.4 Coarse Ore Conveyor Transfers

§ 3.1.2 Potential Emissions Summary [6]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		7.00	40.00	
SO_2				
Pb		3.50E-4		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		1.40	8.00	
Other *(specify)*: As		1.40E-3		
Other *(specify)*: Sb		1.40E-4		
Other *(specify)*: Cr		2.10E-4		
Other *(specify)*: Cd		1.40E-4		
Other *(specify)*:				

[6] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.1 Conveyor to Coarse Ore Stockpile

§ 3.1.2 Potential Emissions Summary [7]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		1.40	8.00	
SO_2				
Pb		7.00E-5		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		0.28	1.60	
Other *(specify)*: As		2.80E-4		
Other *(specify)*: Sb		2.80E-5		
Other *(specify)*: Cr		4.20E-5		
Other *(specify)*: Cd		2.80E-5		
Other *(specify)*:				

[7] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.2 Apron Feeders

§ 3.1.2 Potential Emissions Summary [8]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		0.70	4.00	
SO_2				
Pb		3.50E-5		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		0.14	0.80	
Other *(specify)*: As		1.40E-4		
Other *(specify)*: Sb		1.40E-5		
Other *(specify)*: Cr		2.10E-5		
Other *(specify)*: Cd		1.40E-5		
Other *(specify)*:				

[8] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.3 Conveyor Discharge to SAG Mill

§ 3.1.2 Potential Emissions Summary [9]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(LB/Day)*	
PM_{10}		0.70	4.00	
SO_2				
Pb		3.50E-5		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		0.14	0.80	
Other *(specify)*: As		1.40E-4		
Other *(specify)*: Sb		1.40E-5		
Other *(specify)*: Cr		2.10E-5		
Other *(specify)*: Cd		1.40E-5		
Other *(specify)*:				

[9] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.4 Concentrate Transfer

§ 3.1.2 Potential Emissions Summary [10]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		2.94E-3	1.68E-2	
SO_2				
Pb		1.29E-5		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		5.88E-4	3.36E-3	
Other *(specify)*: As		5.88E-7		
Other *(specify)*: Sb		5.88E-8		
Other *(specify)*: Cr		8.82E-8		
Other *(specify)*: Cd		5.88E-8		
Other *(specify)*:				

[10] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.5 Concentrate Loading

§ 3.1.2 Potential Emissions Summary [11]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		2.94E-3	1.68E-2	
SO_2				
Pb		1.29E-5		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		5.88E-4	3.36E-3	
Other *(specify)*: As		5.88E-7		
Other (*specify)*: Sb		5.88E-8		
Other *(specify)*: Cr		8.82E-8		
Other *(specify)*: Cd		5.88E-8		
Other *(specify)*:				

[11] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.6 Oversize Transfer to Hopper

§ 3.1.2 Potential Emissions Summary [12]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		0.07	0.40	
SO_2				
Pb		3.50E-6		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		1.40E-2	0.08	
Other *(specify)*: As		1.40E-5		
Other *(specify)*: Sb		1.40E-6		
Other *(specify)*: Cr		2.10E-6		
Other *(specify)*: Cd		1.40E-6		
Other *(specify)*:				

[12] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.7 Oversize Reclaim Belt Transfer

§ 3.1.2 Potential Emissions Summary [13]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		0.07	0.40	
SO_2				
Pb		3.50E-6		
NOx				
VOC				
CO				
Other *(specify): $PM_{2.5}$*		1.40E-2	0.08	
Other *(specify):* As		1.40E-5		
Other *(specify):* Sb		1.40E-6		
Other *(specify):* Cr		2.10E-6		
Other *(specify):* Cd		1.40E-6		
Other *(specify):*				

[13] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.8 Oversize Crusher

§ 3.1.2 Potential Emissions Summary [14]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		0.35	2.00	
SO_2				
Pb		1.75E-5		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		0.07	0.40	
Other *(specify)*: As		7.00E-5		
Other (*specify)*: Sb		7.00E-6		
Other *(specify)*: Cr		1.05E-5		
Other *(specify)*: Cd		7.00E-6		
Other *(specify)*:				

[14] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.9 Oversize Screen

§ 3.1.2 Potential Emissions Summary [15]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		0.07	0.40	
SO_2				
Pb		3.50E-6		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		1.40E-2	0.08	
Other *(specify)*: As		1.40E-5		
Other *(specify)*: Sb		1.40E-6		
Other *(specify)*: Cr		2.10E-6		
Other *(specify)*: Cd		1.40E-6		
Other *(specify)*:				

[15] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.10 Belt Transfer Back to SAG Mill

§ 3.1.2 Potential Emissions Summary [16]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		0.07	0.40	
SO_2				
Pb		3.50E-6		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		1.40E-2	0.08	
Other *(specify)*: As		1.40E-5		
Other *(specify)*: Sb		1.40E-6		
Other *(specify)*: Cr		2.10E-6		
Other *(specify)*: Cd		1.40E-6		
Other *(specify)*:				

[16] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.11 Coarse Ore Stockpile Wind Erosion

§ 3.1.2 Potential Emissions Summary [17]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		0.00	0.00	
SO_2				
Pb		0.00		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		0.00	0.00	
Other *(specify)*:				
Other *(specify)*:				
Other *(specify)*:				
Other *(specify)*:				
Other *(specify)*:				

[17] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 2.12 Emergency Generator

§ 3.1.2 Potential Emissions Summary [18]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		2.57E-3	7.72	
SO_2		4.66E-3	13.99	
Pb				
NOx		0.18	549.25	
VOC		5.44E-3	16.31	
CO		8.87E-3	26.60	
Other *(specify):* $PM_{2.5}$		2.57E-3	7.72	
Other *(specify):*				
Other *(specify):*				
Other *(specify):*				
Other *(specify):*				
Other *(specify):*				

[18] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 3.1 Haul Truck Travel

§ 3.1.2 Potential Emissions Summary [19]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		76.18	435.29	
SO_2				
Pb		7.62E-4		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		15.24	87.06	
Other *(specify)*: As		1.52E-2		
Other *(specify)*: Sb		1.52E-3		
Other *(specify)*: Cr		2.30E-3		
Other *(specify)*: Cd		1.52E-3		
Other *(specify)*:				

[19] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 4.1 Tailings Impoundment Wind Erosion

§ 3.1.2 Potential Emissions Summary [20]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		2.05E-3		
SO_2				
Pb		1.02E-7		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		4.09E-7		
Other *(specify)*: As		3.07E-7		
Other *(specify)*: Sb		4.09E-8		
Other *(specify)*: Cr		4.09E-8		
Other *(specify)*: Cd		4.09E-8		
Other *(specify)*:				

[20] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.0 EMISSIONS UNIT SPECIFIC AND PLANT-WIDE EMISSIONS SUMMARY

§ 3.1 Emissions Unit Specific Emission *(Reproduce as necessary)*

§ 3.1.1 Emissions Unit Identification 6.1 Laboratory Crusher

§ 3.1.2 Potential Emissions Summary [21]

Regulated Air Pollutant	Emission Rate(s) (Include any additional applicable units or averaging periods)			
	(Lb/Hour)	*(Tons/Year)*	*(Lb/Day)*	
PM_{10}		0.03	0.16	
SO_2				
Pb		0.00		
NOx				
VOC				
CO				
Other *(specify)*: $PM_{2.5}$		0.01	0.03	
Other *(specify)*:				
Other *(specify)*:				
Other *(specify)*:				
Other *(specify)*:				
Other *(specify)*:				

[21] Include emission rates in units consistent with any applicable standards or test methods. Attach calculations.

§ 3.2 Project-Wide Emission Summary [2]

§ 3.2.1 **Estimated** Increase in **Actual** Emissions from all New or Altered Sources addressed by this application.

This information is used to establish the application fee required. Estimated actual emissions are to be calculated based on the proposed operating schedule and the projected average process rate.

Regulated Air Pollutants	Emission Rate *(Ton/Year)*
PM_{10}	90.38
SO_2	0.15
Pb	0.0015
NOx	3.95
VOC	0.09
CO	65.00
Other (specify): $PM_{2.5}$	18.08
Other (specify):	
Other (specify):	

§ 3.2.2 Total Increase in **Potential** Emissions from those New or Altered Sources addressed by this application.

This table should be a total from the emissions units identified in Section 3.1. Potential emissions are to be calculated based on production at maximum capacity for 8760 hours per year. Only controls which are proposed to be made federally enforceable may be used to limit the potential emissions.

Regulated Air Pollutants	Emission Rate *(Ton/Year)*
PM_{10}	90.38
SO_2	0.15
Pb	0.0015
Nox	3.95
VOC	0.09
CO	65.00
Other (specify): $PM_{2.5}$	18.08
Other (specify):	
Other (specify):	

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 1.1 Blasting – Particulate and Gaseous

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Underground blasting.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone Underground Elevation *(feet)*
UTM Easting Coordinate *(nearest 0.01 km)*
UTM Northing Coordinate *(nearest 0.01 km)*

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed
Average Process Rate or Process Weight
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☐ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 1.1 Blasting – Particulate and Gaseous

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Good blasting practices.

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 1.2 Propane Heaters

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*

Propane heaters to heat underground mine.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description

Sources Classification Code (SCC)

Source Description

(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make

Model

Type

Size

Serial Number

Year of Manufacture

Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone Underground Elevation *(feet)*

UTM Easting Coordinate *(nearest 0.01 km)*

UTM Northing Coordinate *(nearest 0.01 km)*

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*

Diameter *(feet)*

Exit Gas Temperature *(°F)*

Exit Gas Flow Rate *(ACFM)*

Exit Gas Velocity *(feet/second)*

Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☐ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed

Average Process Rate or Process Weight

Maximum Rated Design Capacity

Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type Propane | Heat Content (Btu rating) 90,500 Btu/gal

Average Fuel Combustion Rate 2304 gal/day | Maximum Rated Design Capacity

Sulfur Content *(%)* Negligible | Ash Content *(%)*

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☐ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)*

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)*

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February	25	June - August	25
March - May	25	September - November	25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 1.2 Propane Heaters

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description

Good combustion practices.

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make | Model

Type | Size

Serial Number | Year of Manufacture

Year of Installation | Estimated Control Efficiency

Estimated Cost of Pollution Control Equipment [2]

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make | Model

Type | Size

Serial Number | Year of Manufacture

Year of Installation | Estimated Control Efficiency

Estimated Cost of Pollution Control Equipment [2]

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 1.3 Primary Crushers

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Primary underground crushers to process ore and waste rock.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone Underground Elevation *(feet)*
UTM Easting Coordinate *(nearest 0.01 km)*
UTM Northing Coordinate *(nearest 0.01 km)*

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Ore/Waste Rock
Average Process Rate or Process Weight 827 tons/hr, 7,245,000 tons/yr
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☐ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 1.3 Primary Crushers

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Water Sprays

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Water Sprays Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Startup of Crushers Estimated Control Efficiency 90%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 1.4 Coarse Ore Conveyor Transfers

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Transfers on conveyor taking coarse ore from mine to surface.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone Underground Elevation *(feet)*
UTM Easting Coordinate *(nearest 0.01 km)*
UTM Northing Coordinate *(nearest 0.01 km)*

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Coarse Ore
Average Process Rate or Process Weight 800 tons/hr, 7,000,000 tons/yr
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☐ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February	25	June - August	25
March - May	25	September - November	25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 1.4 Coarse Ore Conveyor Transfers

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Water Sprays

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Water Sprays Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Startup of Conveyor Estimated Control Efficiency 90%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.1 Conveyor to Coarse Ore Stockpile

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Conveyor transfer to stockpile.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11 Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603850
UTM Northing Coordinate *(nearest 0.01 km)* 5329450

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Coarse Ore
Average Process Rate or Process Weight 20,000 tpd, 7,000,000 tpy
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.1 Conveyor to Coarse Ore Stockpile

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Water Sprays

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Water Sprays Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Startup of Mill Estimated Control Efficiency 90%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.2 Apron Feeders

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Apron feeders moving coarse ore from stockpile.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11 Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603850
UTM Northing Coordinate *(nearest 0.01 km)* 5329450

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Coarse Ore
Average Process Rate or Process Weight 20,000 tpd, 7,000,000 tpy
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.2 Apron Feeders

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description

Wet scrubber

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Wet scrubber Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Mill startup Estimated Control Efficiency 95%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.3 Conveyor Discharge to SAG Mill

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Conveyor discharge to mill building.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11 Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603900
UTM Northing Coordinate *(nearest 0.01 km)* 53296

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Coarse Ore
Average Process Rate or Process Weight 20,000 tpd, 7,000,000 tpy
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.3 Conveyor Discharge to SAG Mill

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Wet scrubber

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Wet scrubber Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Mill startup Estimated Control Efficiency 95%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.4 Concentrate Transfer

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Concentrate transfer to loadout.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11 Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603900
UTM Northing Coordinate *(nearest 0.01 km)* 5329600

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Ore Concentrate
Average Process Rate or Process Weight 420 tpd, 147,000 tpy
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February	25	June - August	25
March - May	25	September - November	25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.4 Concentrate Transfer

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____
Enclosure

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Enclosure Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency 99%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.5 Concentrate Loadout

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*

Concentrate loadout to trucks

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description

Sources Classification Code (SCC)

Source Description

(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make

Model

Type

Size

Serial Number

Year of Manufacture

Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11

Elevation *(feet)* 4357

UTM Easting Coordinate *(nearest 0.01 km)* 603900

UTM Northing Coordinate *(nearest 0.01 km)* 5329600

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*

Diameter *(feet)*

Exit Gas Temperature *(°F)*

Exit Gas Flow Rate *(ACFM)*

Exit Gas Velocity *(feet/second)*

Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*

☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent

☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Ore Concentrate

Average Process Rate or Process Weight 420 tpd, 147,000 tpy

Maximum Rated Design Capacity

Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February	25	June - August	25
March - May	25	September - November	25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.5 Concentrate Loading

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Enclosure

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Enclosure Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency 99%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.6 Oversize Transfer to Hopper

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Oversize ore transfer to oversize hopper.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11 Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603900
UTM Northing Coordinate *(nearest 0.01 km)* 5329600

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Oversize Ore
Average Process Rate or Process Weight 1,000 tpd, 350,000 tpy
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.6 Oversize Transfer to Hopper

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Water Sprays

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Water Sprays Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Startup of Mill Estimated Control Efficiency 90%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.7 Oversize Reclaim Belt Transfer

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Oversize reclaim belt transfer point.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11
Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603900
UTM Northing Coordinate *(nearest 0.01 km)* 5329600

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Oversize ore
Average Process Rate or Process Weight 1,000 tpd, 350,000 tpy
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February	25	June - August	25
March - May	25	September - November	25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.7 Oversize Reclaim Belt Transfer

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Water Sprays

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Water Sprays Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Startup of Mill Estimated Control Efficiency 90%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.8 Oversize Crusher

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Oversize ore crusher.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11 Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603900
UTM Northing Coordinate *(nearest 0.01 km)* 5329600

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Oversize ore
Average Process Rate or Process Weight 1,000 tpd, 350,000 tpy
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.8 Oversize Crusher

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Water Sprays

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Water Sprays Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Startup of Mill Estimated Control Efficiency 90%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.9 Oversize Screen

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Screening of oversize ore

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11 Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603900
UTM Northing Coordinate *(nearest 0.01 km)* 5329600

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Oversize ore
Average Process Rate or Process Weight 1,000 tpd, 350,000 tpy
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.9 Oversize Screen

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Water Sprays

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Water Sprays Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Startup of mill Estimated Control Efficiency 90%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.10 Belt Transfer Back to SAG Mill

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Belt transfer from oversize crushing/screening train to SAG mill.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11 Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603900
UTM Northing Coordinate *(nearest 0.01 km)* 5329600

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Oversize ore
Average Process Rate or Process Weight 1,000 tpd, 350,000 tpy
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.10 Belt Transfer Back to SAG Mill

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Water Sprays

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Water Sprays Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Startup of Mill Estimated Control Efficiency 90%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 2.11 Coarse Ore Stockpile Wind Erosion

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Wind erosion of coarse ore stockpile

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11 Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603850
UTM Northing Coordinate *(nearest 0.01 km)* 5329450

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Coarse Ore
Average Process Rate or Process Weight 20,000 tpd, 7,000,000 tpy
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 2.11 Coarse Ore Stockpile Wind Erosion

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Water Sprays

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Water Sprays Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Startup of Mill Estimated Control Efficiency 90%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 3.1 Haul Truck Travel

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Haul truck travel from mill to rail siding in Libby.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone Haul Road Elevation *(feet)*
UTM Easting Coordinate *(nearest 0.01 km)*
UTM Northing Coordinate *(nearest 0.01 km)*

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*
Stack Type *(check one)* ☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap
Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Concentrate Haulage
Average Process Rate or Process Weight 21 trips per day, 7,350 trips per year
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 3.1 Haul Truck Travel

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

Sealed Road

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Sealed Road Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 4.1 Tailings Impoundment Wind Erosion

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Wind erosion of the tailings impoundment.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11 Elevation *(feet)* 3600
UTM Easting Coordinate *(nearest 0.01 km)* 607930
UTM Northing Coordinate *(nearest 0.01 km)* 5336570

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)*
☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Tailings
Average Process Rate or Process Weight 800 acres
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February	25	June - August	25
March - May	25	September - November	25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 4.1 Tailings Impoundment Wind Erosion

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description

Partially Submerged, Sprinklers

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type Sprinklers Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation Start of production Estimated Control Efficiency 50%

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 4.0 EMISSIONS UNIT/PROCESS INFORMATION

§ 4.1 Emissions Unit Identification 6.1 Laboratory Crusher

§ 4.2 Narrative Process Equipment/Process Description *(attach additional sheets as necessary)*
Laboratory crusher used for small scale lab analysis.

§ 4.3 Proposed Operational Limitations *(if any)*

§ 4.4 Emissions Unit Description
Sources Classification Code (SCC)
Source Description
(SCC Code and Description list available from the DEQ)

Title IV Affected Unit ☐ Yes ☒ No

Process Equipment Identification

Make
Model
Type
Size
Serial Number
Year of Manufacture
Year of Installation

Emitting Unit Location *[Note: UTM coordinates are available on any USGS map]*

Universal Transverse Mercator *(UTM)* Zone 11
Elevation *(feet)* 4357
UTM Easting Coordinate *(nearest 0.01 km)* 603900
UTM Northing Coordinate *(nearest 0.01 km)* 5329600

Stack and Exit Gas Information *(if applicable)*

Height *(feet)*
Diameter *(feet)*
Exit Gas Temperature *(°F)*
Exit Gas Flow Rate *(ACFM)*
Exit Gas Velocity *(feet/second)*
Exit Gas Moisture Content *(%)*

Stack Type *(check one)*
☐ Downward Exit ☐ Multiple Actual Stacks ☒ Fugitive Source *(No Stack)*
☐ Horizontal Exit ☐ Building Roof Vent ☐ Process Vent
☐ Vertical Exit ☐ Vertical Exit with Cap

Stack Lining *(check one)* ☐ Metal ☐ Refractory ☐ Other *(specify)*

Process Information *(Indicate Units)*

Type of Material Processed Ore
Average Process Rate or Process Weight 1 tpd
Maximum Rated Design Capacity
Approximate Quantities Produced *(if source is temporary)*

Fuel/Combustion Information

Fuel Type _____ Heat Content (Btu rating) _____

Average Fuel Combustion Rate _____ Maximum Rated Design Capacity _____

Sulfur Content *(%)* _____ Ash Content *(%)* _____

Draft Type *(check one)* ☐ Forced ☐ Induced ☐ Natural ☐ Combination ☒ None

Draft Control *(check one)* ☐ Barometer ☐ Sliding Door ☐ Butterfly ☐ Guillotine

☐ Other *(specify)* _____

Draft Control Location ☐ Up Pass Breeching ☐ Five Connector

☐ Other *(specify)* _____

Percent Annual Thruput *(Percent of the applicant's work done in each time frame. The percentages entered for the four time frames must add up to 100%.)*

December - February 25 June - August 25

March - May 25 September - November 25

§ 5.0 EMISSIONS UNIT AIR POLLUTION CONTROL

§ 5.1 Process Unit Identification 6.1 Laboratory Crusher

§ 5.2 Pollution Control Equipment and Practices

§ 5.2 1 Primary and Secondary Pollution Control Equipment or Procedure Description _____

None

§ 5.2.2 Primary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

§ 5.2.3 Secondary Air Pollution Control Equipment Identification *(if applicable)*

Make _____ Model _____

Type _____ Size _____

Serial Number _____ Year of Manufacture _____

Year of Installation _____ Estimated Control Efficiency _____

Estimated Cost of Pollution Control Equipment [2] _____

[2] Not required for operating permit applications

§ 5.3 Continuous Emission Monitoring System #1 Identification *(if applicable)*

Type *(check one)* ☐ Opacity SO_2 ☐ NO_x ☐ O_2 ☐ CO ☐ CO_2 ☐ TRS
☐ Other *(specify)* _____

Make _____ Model _____
Serial Number _____
Automatic Calibration Valve: Zero _____ Span _____

§ 5.3 1 Continuous Emission Monitoring System #2 Identification *(if applicable)*

Type: *(check one)* ☐ Opacity SO_2 ☐ NO_x ☐ O_2 ☐ CO ☐ CO_2 ☐ TRS
☐ Other *(specify)* _____

Make _____ Model _____
Serial Number _____
Automatic Calibration Valve: Zero _____ Span _____

§ 5.3 2 Continuous Emission Monitoring System #3 Identification *(if applicable)*

Type *(check one)* ☐ Opacity SO_2 ☐ NO_x ☐ O_2 ☐ CO ☐ CO_2 ☐ TRS
☐ Other *(specify)* _____

Make _____ Model _____
Serial Number _____ Year of Manufacture _____
Automatic Calibration Valve Zero _____ Span _____

§ 5.4 [2] Emissions Control Analysis

Provide a Best Available Control Technology (BACT) or Lowest Achievable Emission Rate (LAER) Analysis as applicable. Address each regulated air pollutant.

§ 5.5 Stack Height and Dispersion Technique Analysis

If applicable, supply an analysis demonstrating compliance with the requirements of the stack height and dispersion technique rules.

[2] Not required for operating permit applications

§ 6.0 REGULATORY PROGRAMS

Applicable Air Pollution Control Programs *(check all that apply)*

- ☒ Air Quality Preconstruction Permits
- ☐ Prevention of Significant Deterioration (PSD)
- ☐ Air Quality Operating Permits (Title V)
- ☐ Major Source (> 100 TPY)
- ☐ Non-Attainment Area
- ☒ Regulated Air Pollutant(s) PM_{10}, $PM_{2.5}$ ☒ Located in, or ☐ Causing or contributing to
- ☒ New Source Performance Standards (NSPS) (*specify applicable subpart(s) and identify affected facilities)*
  40 CFR, Part 60, Subpart LL, Metallic Minerals Processing
- ☐ NESHAPS *(specify)* _____
- ☐ Title III Hazardous Air Pollutants (HAPs) [>10 TPY of any single HAP or 25 TPY of a combination of all HAPs combined]
- ☐ Maximum Achievable Control Technology (MACT)
- ☐ Title IV (Acid Rain) Affected Source
- ☐ Other(s) *(specify)* _____

§ 7.0 APPLICABLE REQUIREMENTS

§ 7.1 Applicable Requirements *(if applicable)*

Attach a complete listing of all applicable requirements. (see permit application Table 1.1)

§ 7.2	Additional Requirements	Required	Submitted
§ 7.2.1 [2]	Ambient Air Quality Impact Analysis	☒	☒
§ 7.2.2 [2,4]	Alternative Siting Analysis	☐	☐
§ 7.2.3 [5]	Alternative Operating Scenario	☐	☐
§ 7.2.4 [6]	Compliance Schedule/Plan	☐	☐
§ 7.2.4	Compliance Certification	☐	☐
§ 7.2.6 [7]	Additional requirements for solid or hazardous waste incinerators or BIFS subject to 75-10-406 MCA.	☐	☐
§ 7.2.6 [8]	Additional Requirements for Commercial Medical and Commercial Hazardous Waste Incinerators including BIFS Subject to 75-10-406 MCA.	☐	☐

[2] Not required for operating permit applications

[4] Only required for air quality preconstruction permits for major stationary sources located in a nonattainment area or for major stationary sources located in an area designated as attainment or unclassified for a national ambient air quality standard (NAAQS) under 40 CFR 81.327 but would cause or contribute to a violation of a NAAQS in a nearby nonattainment area (i.e., for those sources required to obtain an air quality preconstruction permit and required to comply with the requirements of subchapters 17 and 18).

[5] Not required for air quality preconstruction permit applications.

[6] Only required for air quality operating permit applications for sources already operating.

[7] Required only for preconstruction permit applications for Solid or Hazardous Waste Incinerators or BIFS Subject to 75-10-406 MCA.

[8] Required only for preconstruction permit applications for Commercial Medical and Commercial Hazardous Waste Incinerators Including BIFS Subject to 75-10-406 MCA.

§ 8.0 INSTRUCTIONS ON PUBLIC NOTICE FOR AIR QUALITY PRECONSTRUCTION PERMIT

The applicant shall publish the following notification no earlier than 10 days prior to the date the applicants air quality preconstruction permit application will be submitted to the Department, and no later than 10 days following the date of submittal. The notice shall be published **once** in the legal notice section of a newspaper of general circulation in the area affected. Any fees associated with publication of this notice are the responsibility of the permit applicant. Questions regarding an appropriate newspaper should be addressed to the Department. An Affidavit of Publication of Public Notice must be submitted with the application or the air quality preconstruction permit application will be deemed incomplete. This notice is required by the air quality rules. **The notice to be published consists of the exact language, excluding the text in italics, within the box below.**

PUBLIC NOTICE

Notice of Application for Air Quality Preconstruction Permit (pursuant to Sections 75-2-211, and 75-2-215 MCA, and the Air Quality Rules).

_____
Name of applicant(s)

_____ on or about _____ an application for a air quality
has filed/will file *date*

preconstruction permit or an alternation to an existing air quality preconstruction permit from the Montana Department of Environmental Quality. Applicant(s) seeks approval of its application for:

_____

_____

_____

_____

(brief description of source for which permit is being applied, and the site location including
1) a narrative description related to nearby towns, roads, landmarks, etc., and
2) the legal description of section, township, range, and county)

Within 40 days of the receipt of a completed application, the Department will make a preliminary determination whether the permit should be issued, issued with conditions, or denied. Any member of the public with questions or who wishes to receive notice of the preliminary determination, and the location where a copy of the application and the DEQ's analysis of it can be reviewed, or to submit comments on the preliminary determination, must contact the DEQ at Department of Environmental Quality, Air Resources Management Bureau, Air Permitting Section Supervisor at P.O. Box 200901, Helena, Montana 59620-0901, telephone (406) 444-3490. Any comments on the preliminary determination must be submitted to the department within 15 days after the preliminary determination is issued.

§ 9.0 CERTIFICATION OF ACCURACY AND COMPLETENESS

I hereby certify that, to the best of my knowledge, information and belief, formed after reasonable inquiry, the information provided in this permit application is true, accurate and complete.

(Name, title and signature of corporate officer, responsible official, authorized representative, or designated representative under Title IV 1990 FCAA.)

Name Eric Klepfer
(Print of Type)

Title Vice President Telephone 509-838-6050

Signature *(Original Signature Required)* **Date** 1/13/06

Project and Site Informational Request
Department of Environmental Quality
Air Resources Management Bureau
P.O. Box 200901, Helena, MT 59620-0901
Telephone: (406) 444-3490 FAX: (406) 444-1499

Instructions:	Please answer the questions listed below in reference to the current project proposed in the air quality permit application. Please attach additional pages if necessary. The Department will use the information to facilitate completion of an environmental analysis required under the Montana Environmental Policy Act (MEPA).

Facility Name: **A supplemental EIS for the Montanore Mine is currently under development by the USFS.**

1. Please summarize fish or wildlife habitat, animal or bird species, or any known migration or movement of animals at the project site.

2. Please describe any proposed discharges into surface water or onto the site; any changes in drainage patterns; any use of surface water and groundwater; and any potential impacts to wetlands.

3. Please summarize the soils and geology of the project site. Include a description of any disruption, displacement, erosion, compaction, moisture loss, or over-covering of soil that would reduce productivity or fertility at the site. The description should include the amount of land disturbed in acres. Please describe any destruction or modification of any unique geologic or physical feature.

4. Please summarize the plant species (including types of trees, shrubs, grasses, crops, and aquatic plants) at the site. The applicant should include a description of any known unique, rare, threatened, or endangered plant species at the site. In addition, please describe the land use at the project site.

5. Please summarize the aesthetic character of the project site and of the surrounding community or neighborhood. Include a description of recreational opportunities. Also include a description of noise levels created by the proposed project.

6. Please describe any unique, rare, threatened, or endangered animal species that are at or near the site.

7. Please describe any upgrading of utilities that may result from power demands from this project.

8. Please describe any known historical, archaeological, or paleontological sites at the project site.

9. Please summarize other industrial activities at or near the site, or any other permits that you hold which are, or may be, in effect at this site.

10. Please indicate the number of employees currently employed and the increase or decrease in the number of people employed at the site as a result of the proposed project.

11. Please describe any unique cultures in the area that may be affected by the proposed application.

12. Please summarize any access to recreational or wilderness activities near the project site.

13. Please describe any state, county, city, USFS, BLM, or tribal zoning or management plans and goals that might affect the site.

14. Please indicate who owns the land at the proposed project site.

15. Please indicate the approximate distance to the nearest home or structure not associated with the project site.

APPENDIX B

MODELING PROTOCOL AND RELATED DOCUMENTATION

September 27, 2005

Mr. Eric Thunstrom
Montana Department of Environmental Quality
PO Box 200901
Helena, MT 59620-0901

Subj: Mines Management Inc. Montanore Mine Project
Minor Source Permit Application
Modeling Analysis Protocol

Dear Eric,

Mines Management, Inc. (Mines Management) is proposing the development of the Montanore Mine, an underground silver and copper mine to be located in Lincoln County 15 miles south-southwest of Libby. Mines Management will be submitting to MDEQ a minor source permit application pursuant to ARM Title 17 Chapter 8 Subchapter 7.

TRC Environmental Corporation (TRC) has been contracted by Mines Management to prepare the minor source air quality permit application. The application will include an air dispersion modeling analysis to demonstrate compliance with ambient standards as generally required under ARM 17.8.748(j) and 17.8.749(3) and following the requirements outlined in Montana Modeling Guideline for Air Quality Permits, November 2002 Draft (Montana Guideline). This letter serves as a modeling protocol which presents a description of the data and modeling methodologies proposed for use in the Montanore Mine dispersion modeling analysis. The remainder of this letter provides a brief description of the project, emission rates to be modeled, model selection and settings, meteorological data selection, and other procedures for modeling demonstrations required or requested by MDEQ to be included in the air quality permit application.

PROJECT OVERVIEW

Mines Management Inc. proposes to develop and operate a 20,000 tons per day (tpd) underground silver and copper mine and associated mill. Mine facilities will be located in the Kootenai National Forest, approximately 15 miles south-southwest of Libby and just east of the Cabinet Mountains Wilderness Area. The facilities will generally consist of underground mining and primary crushing, conveyor transfer to surface, and a mill which will produce concentrate for shipment to a rail load-out facility in Libby. Two portals will exhaust underground point and fugitive source emissions: the Ramsey Portal will be located adjacent to the mill site, and the Libby Portal will be south and west of the mill. Tailings slurry from the mill process will be piped to the tailings impoundment located north of the mill site.

The general location of the mine facilities and regional terrain is shown in Figure 1, attached. The mill facility is shown in greater detail in Figure 2.

PROJECT EMISSIONS

A preliminary criteria pollutant emissions inventory has been prepared and is presented in Table 1, attached. This inventory is subject to change if mine design or other variables require revision during the application preparation process. The facility will be classified as a PSD minor source and will not be subject to PSD permit requirements under ARM 17.8.800. Once constructed, the facility will be a minor source under the Montana operating permit program as defined in ARM 17.8.1201(23).

Air emissions of PM_{10}, $PM_{2.5}$, NO_x, CO, and SO_2 from mine production operations, shown in Table 1, were calculated using AP-42, manufacturer's emission data, or other accepted engineering methods in combination with material throughputs, equipment operating rates, and other operations data. Air emissions from underground operations will occur from blasting and crushing operations, propane heaters operating underground, diesel-fired mobile sources, and conveying ore to the surface. Air emissions from surface operations will occur from mill operation (ore handling and processing), concentrate haulage, surface operations-related mobile sources, and wind erosion at the tailings impoundment. More detail on equipment, control devices/methods, and emission calculations will be provided in the air quality permit application. Although $PM_{2.5}$ is not yet regulated by MDEQ, emissions for this pollutant are calculated due to pending $PM_{2.5}$ nonattainment area status in the vicinity of the nearby town of Libby. Lead (Pb) emissions are also calculated in Table 1, and are discussed further below.

Based on an ore and tailings metals assay conducted at a similar regional mine, these materials may contain trace amounts of the metals arsenic, antimony, cadmium, chromium, and lead, defined as Hazardous Air Pollutants (HAPs) under section 112(b) of the Federal Clean Air Act. Particulate emissions from the processing or wind erosion of ore or tailings are used in conjunction with assay results to determine potential emissions of these HAPs, and preliminary results of this emissions inventory are shown in Table 2 (lead is shown in Table 1). HAP emissions will be examined in a risk assessment as described later in this protocol.

Pollutant emissions from the portion of concentrate haul truck travel which occurs off-site and from the concentrate load-out facility to be located in the town of Libby, MT, are not proposed to be modeled in this analysis. Concentrate haul truck emissions from travel on paved roads are small (0.5 lb/vehicle mile traveled) and are distributed over a 20-mile segment of road, and particulate emissions from the load-out facility are expected to be negligible because the concentrate will be wet and the facility will be completely enclosed. The potential wind-blown emissions from concentrate spillage onto road or other surfaces outside the enclosure, and proposed mitigation to minimize particulate emissions from that or other potential sources, will be addressed in the permit application.

A diesel electric generator will be in use on the surface during the construction phase of the mine, with one engine operating at full load 8,760 hours per year and one on standby. Because line power will be available within the first year of construction and prior to commencement of underground mining operations, no power generation will be required during production. One emergency generator will remain on standby at the site after the construction phase to provide power in the event of an outage.

MODELING METHODOLOGY

A dispersion modeling analysis will be performed to quantify PM_{10}, $PM_{2.5}$, NO_2, SO_2, and lead impacts and demonstrate that operation of the Montanore Mine will comply with Montana and National Ambient Air Quality Standards (MAAQS/NAAQS) defined in the Montana Guideline Table 5.4. Because NOx modeling is to be performed for all emission sources, no CO modeling is proposed (Montana Guideline Table 1.1). This modeling analysis will be performed following guidance contained in the Montana Guideline and in accordance with EPA guidance set forth in the Guideline on Air Quality Models (GAQM, 40 CFR Part 51 Appendix W). The modeling analysis will also be performed to analyze PM_{10} and $PM_{2.5}$ concentrations along the PM_{10} nonattainment boundary and proposed $PM_{2.5}$ nonattainment boundary, respectively, as an indicator of significance of contribution to ambient air quality in those nonattainment areas. In addition, a modeling analysis will be performed to assess human health risk from trace metals identified as HAPs. The analysis will calculate modeled concentrations of lead, arsenic, antimony, cadmium, and chromium.

Model Selection

EPA's guideline model, ISCST3 (Version 02035), is proposed to assess pollutant impacts. The terrain surrounding the Montanore Mine is characterized as complex, and features terrain both above and below source release heights. The ISCST3 model is characterized in EPA's GAQM as a screening level model for complex terrain. Screening level models are intended to provide conservative results using limited data assumed to be representative of worst-case conditions. Screening level modeling results are generally accepted and regarded as protective of the ambient standards addressed.

Model Switch Settings

The land use within a three-kilometer radius surrounding the Montanore facility is characterized as rural; therefore, the rural dispersion option will be used for the ISCST3 model. Missing meteorological data over the modeling period will be handled using ISCST3's missing data option, MSGPRO. Regulatory defaults will be used for all other switch settings in accordance with EPA's GAQM.

Modeled Emission Rates

Emission rates described under the project emissions section of this protocol will be modeled. Maximum short-term emission rates will be modeled for comparison to short-term averaging period standards, and annual average emission rates will be modeled for comparison to annual averaging period standards. No other industrial sources are known to be located near the Montanore Mine: therefore, only the Montanore Mine will be modeled.

Calculated criteria pollutant emissions from underground sources were assumed to be subject to some level of deposition en route to the mine portals. Deposition in the mine was calculated using the Van derHoven equations discussed in "Meteorology and Atomic Energy" (Slade, 1968). The equations were solved iteratively or from figures presented in Slade, 1968 as a function of stability class, wind speed, and deposition velocity. Deposition velocities were obtained from Table 12.5 of "Atmospheric Science and Power Production" (Sehmel, 1984). An assumption was made that the ventilation velocity in the mine would be 1.0 m/s and there would be limited vertical air-flow since airflow in the mine is confined to the portals. Therefore an atmospheric stability of "F" was justified.

The majority of underground emissions at the Montanore mine occur an average of 19,000 ft from the exhaust portal. Using these parameters for the graph on Figure 5.5 (Slade, 1968), a source depletion fraction was obtained. Using Equation 5.49 (Slade, 1968) to adjust for pollutant specific deposition velocity, an escape fraction for each pollutant was obtained. Based on the calculation method described above, it was found that approximately 65% of the NO_x, 20% of the SO_2, and 4% of the particulate matter greater than 2.5 microns in size would escape the mine portals. 100% of CO and particulate matter less than 2.5 microns were conservatively assumed to escape.

Source Idealization

Modeled sources were placed at locations reflective of the mine plan and infrastructure. Table 3 provides stack parameters proposed for use in the modeling analysis and their basis. Figure 3 illustrates the location and size of each modeled source. No stacks are anticipated to be horizontal or equipped with rain caps. The closest modeled source to any facility boundary is MSUREQP3 within the Ramsey Mill boundary, located 130 meters from the facility boundary.

Building Downwash Analysis

An initial analysis of potential building aerodynamic downwash was performed to determine any effect on the Ramsey Portal release from the mill facility building, the largest structure to be located at the mill site. No structures will be located at the Libby Portal site. The analysis was performed using the current regulatory version of the Building Profile Input Program (BPIP).

BPIP results indicated that no downwash effects would occur; therefore, no building downwash is proposed to be included in the model. BPIP input and output files are included on CD-ROM with this protocol.

Model Receptors

The Montanore Mine public access boundaries are shown in Figure 1, and surround the Ramsey Portal and Mill facility, Libby Portal, Land Application Development areas, and Tailings area. These boundaries are comprised of USFS lands immediately surrounding mine-related activities for which a surface lease has been granted by USFS, and public access will be limited in these areas to preserve public health and safety. Public access will be limited by physical barriers (i.e., gates) on accessible roadways and by posting of no admittance at regular intervals.

Receptors for criteria pollutant compliance and HAP risk assessment modeling will be placed at 50m intervals along public access boundaries. A 100m cartesian receptor grid will extend to 1 km in each direction beyond these boundaries, a 250m cartesian grid will extend to 3 km in each direction, a 500m cartesian grid will extend to 5 km in each direction, and receptors at 100m intervals will be placed along the Cabinet Mountains Wilderness Area boundary. Compliance/Risk Assessment modeling receptor locations are illustrated in Figure 4. In addition, receptors will be placed at 100m intervals along the PM_{10} and $PM_{2.5}$ nonattainment area boundaries. Nonattainment area boundary receptors are illustrated in Figure 5.

Terrain heights for all features will be assigned using USGS Digital Elevation Models in 1:24,000 scale including Barren Peak, Cable Mountain, Elephant Peak, Goat Peak, Horse Mountain, Howard Lake, Noxon Rapids Dam, Silver Butte Pass, and Snowshoe Peak. All facility locations and DEM data will be developed in NAD27.

Meteorology Data

On-site meteorology was collected at a site in the upper Ramsey Creek drainage at the Montanore mill site from July 1, 1988 through June 30, 1989, as part of a previous permit effort for the mine (see *Air Quality Permit Application for Noranda's Montanore Project Volume I Permit Application*, TRC Environmental Consultants, Inc. dated October 16, 1989). A 10-meter tower collected wind speed, wind direction, sigma-theta, and temperature in a forest clearing at this site, and these data are proposed for use in this modeling analysis. Meteorological data was also collected at a site on Little Cherry Creek near the proposed tailings pond; however, because data recovery at this site is not as complete as the Ramsey Creek site, and because a majority of pollutant emissions will be emitted from the Ramsey and Libby Portals of which the Ramsey Creek meteorological data is more representative, the Little Cherry Creek data is not proposed for use in this analysis. The Ramsey Creek and Little Cherry Creek meteorological monitoring sites are shown in Figure 1, attached.

The Ramsey Creek meteorological data was combined with twice-daily upper air mixing height data from Spokane, WA, the closest upper air meteorological site to the mine, and was processed using EPA's Meteorological Processor for Regulatory Models (MPRM). Data recovery at the site was 88.7% for quarter 3 1988, 93.5% for quarter 4 1988, 99.95% for quarter 1 1989, 92.8% for quarter 2 1989, and 93.7% for the period of record. This data recovery meets EPA monitoring guidance in place at the time the data was collected, at least 90% recovery over 12 consecutive months. A windrose is provided as Figure 6 which illustrates the frequency of occurrence of wind speed and wind direction at the Ramsey site. The meteorological dataset is included on CD-ROM with this protocol.

Concentration Comparisons

The second-highest modeled concentrations will be compared to MAAQS/NAAQS expressed as short-term averaging periods and the highest modeled concentrations will be compared to MAAQS/NAAQS expressed as quarterly and annual averaging periods. Because quarter 3 1988 of the Ramsey Creek meteorological dataset exhibited 88.7% data recovery, the Ramsey Creek dataset does not meet the current EPA meteorological monitoring requirement of 4 consecutive quarters at 90% data recovery. However, this methodology follows GAQM design concentration guidance with consideration for the fact that the meteorological dataset proposed (Ramsey Creek) met EPA monitoring requirements in place at the time the data was collected.

Modeled concentrations at the Cabinet Mountains Wilderness Area PSD Class I Area boundary and within the wilderness area will be compared to PSD Class I Increments established by EPA and set forth in the Montana Guideline Table 5.5. Modeled concentrations of PM_{10} and $PM_{2.5}$ at the Libby nonattainment boundaries for each respective pollutant will be compared to the proposed PSD Class II significance levels for PM_{10}, and the equivalent of 2% of the proposed ambient air quality standard for $PM_{2.5}$. HAP concentrations will be calculated at MAAQS/NAAQS receptor locations as part of the risk assessment performed. Because no Montana guidance exists for a risk assessment for this facility type, concentrations are proposed to be compared to the risk assessment levels defined for incinerators in ARM 17.8.770 Tables 1 and 2, as applicable, for carcinogens and non-carcinogens.

NOx to NO_2 Conversion

The Ambient Ratio Method (ARM) will be used to convert most modeled NOx concentrations to NO_2 concentrations for comparison to MAAQS and NAAQS. Modeled NOx concentrations will be multiplied by 0.75 to calculate NO_2 concentrations for all standards except the 1-hour MAAQS. For the 1-Hour MAAQS, the Ozone Limiting Method (OLM) will be utilized. An ozone background of 196 $\mu g/m^3$, equivalent to the 1-Hour ozone standard, is proposed to be used in the equation described in Step 2 of Appendix C – Estimating NO_2 Emissions, from the Montana Guideline.

Ambient Background Concentrations

Background pollutant concentrations have been established for this project through a NEPA Plan of Study approved by MDEQ in a letter dated July 12, 2005. These background concentrations are shown in Table 4, and will be combined with modeled concentrations from mine operations to arrive at a total ambient air quality impact for comparison to MAAQS/NAAQS. Comparison of modeled concentrations occurring at the Cabinet Mountains Wilderness Class I Area to Class I significance levels will not include background concentrations, nor will the comparison of modeled concentrations at particulate nonattainment boundaries to Class II significance levels.

Visibility Analysis

Visibility impact assessment requirements set forth in ARM 17.8.11 apply to PSD major sources. Although the Montanore Mine will be classified as a PSD minor source, due to the close proximity (0.25 mi) of the mine portals to the Cabinet Mountains Wilderness Area, a PSD Class I Area, an analysis of the proposed project's impact to visibility impairment is proposed. The EPA Guideline on Air Quality Models and Federal Land Managers' Air Quality Related Values Workgroup (FLAG) document recommend use of the VISCREEN model for predicting visual plume impacts at distances less than 50 kilometers from a source, and the PLUVUE II model is recommended as a more refined method for these calculations. These two models calculate the change in color difference index (ΔE) and contrast between the plume and the viewing background. The results of the modeling analyses will be compared to the significance levels provided in the FLAG report, which are stated as follows:

> *"If a screening analysis of a new or modified source can demonstrate that its emissions will not cause a plume with any hourly estimates of ΔE greater than or equal to 2.0, or the absolute value of the contrast values ($|C|$) greater than or equal to 0.05, the FLM is not likely to object to the issuance of the PSD permit based on near field visibility impacts and no further near field visibility analyses will be requested. More refined analyses (i.e., PLUVUE II) would be compared against lower levels of concern; the FLM would not likely object if $\Delta E < 1.0$ and $|C| < 0.02$. If the estimated plume parameters exceed the aforementioned values, the FLM would rely on a case-by-case effects-based test (NPS 1993), taking into account magnitude, frequency, duration, and other factors, to decide whether to make an adverse impact determination."*

TRC proposes to perform independent visual plume impacts modeling analyses for both the Ramsey and Libby exhaust portals. Emissions from each portal will be used to estimate the potential impacts to visibility at the Cabinet Mountains Wilderness Area. The VISCREEN model will be used for the initial screening analyses. A Level 1 analysis, which uses screening meteorology, will be performed and, if necessary, a Level 2 analysis, which uses representative meteorology, will be performed. If analyses beyond VISCREEN are required, the PLUVUE II

model will be used to determined discrete plume impacts to visibility. Single view points within the Cabinet Mountains Wilderness Area will be selected for each portal analysis. The view points will be selected based on the maximum possible and likely viewing distances within the Class I area based on the terrain and source location geometry. PLUVUE analyses will be performed using representative hourly meteorology from the Ramsey site.

MODELING RESULTS REPORT

The modeling analysis will be summarized in a written modeling report which will be submitted to MDEQ with the permit application document. The modeling report will describe the final emissions inventory and any other details not available for this protocol, will document compliance status relative to MAAQS and NAAQS, and will discuss results of other impact analyses described herein. Modeled concentrations for all pollutants analyzed, background values, maxima locations, and ambient standards/significance levels will be reported in tables and discussed in the text. Modeled criteria pollutant concentration isopleths will illustrate the concentration gradient within the modeled receptor grid. Electronic copies of the data and model input and output files relied upon to demonstrate compliance with all applicable standards will be provided on CD-ROM in accordance with the Montana Modeling Guideline.

Thank you for the opportunity to present this protocol for MDEQ review. Please feel free to contact me at (308) 764-2550 if you have questions as you perform your review of this protocol.

Sincerely,

TRC ENVIRONMENTAL CORPORATION

Susan Connell

Susan J. Connell
Air Quality Scientist

cc: E. Klepfer, Mines Management
file

Attachments

Mines Management Inc. Contact Information:

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Vice President Environmental Affairs
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(509) 838-6050

TABLES, FIGURES, and ATTACHMENTS

Table 1 - Preliminary Criteria Pollutant Inventory

Source ID Number	Description	General Location	Point or Fugitive	Annual Throughput	Units	Maximum Short-Term Throughput	Units	Controls	Accounted for Deposition?	Annual PM_{10} Emissions (tpy)	24-Hour PM_{10} Emissions (lb/day)	Annual $PM_{2.5}$ Emissions (tpy)	24-Hour $PM_{2.5}$ Emissions (lb/day)	Annual NO_x Emissions (tpy)	24-Hour NO_x Emissions (lb/day)	Annual CO Emissions (tpy)	24-Hour CO Emissions (lb/day)	Annual SO_2 Emissions (tpy)	24-Hour SO_2 Emissions (lb/day)	Annual VOC Emissions (tpy)	24-Hour VOC Emissions (lb/day)	Annual Lead Emissions (tpy)
1 Mine Sources																						
1.1	Blasting - Particulate	Underground	F	3,750	blasts/yr	14.71	blasts/day	Good blasting practices	Y	0.04	0.22	0.02	0.13	--	--	--	--	--	--	--	--	1.93E-06
	Blasting - Gaseous	Underground	F	4,775.5	tpy	13.64	tpd	Good blasting practices	N	--	--	--	--	0.86	4.92	64.66	369.50	0.03	0.16	--	--	--
1.2	Propane Heaters	Underground	P	347,900	gal/yr	2,304.00	gal/day	Good combustion practices	N	0.07	0.92	0.07	0.92	1.59	13.73	0.33	4.38	5.57E-04	1.47E-03	0.09	1.15	--
1.3	Primary Crushers	Underground	P	7,245,000	tons/yr	827.05	tons/hr	Venturi Scrubber	Y	0.76	4.32	0.65	3.73	--	--	--	--	--	--	--	--	3.78E-05
1.4	Coarse Ore Conveyor Transfers	Underground	P	7,000,000	tons/yr	799.09	tons/hr	Water Sprays	Y	1.62	9.28	1.40	8.00	--	--	--	--	--	--	--	--	8.12E-05
1.5	Underground Mobile Sources	Underground	F					None	N	2.30	13.17	2.30	13.17	63.70	363.97	34.95	199.72	3.90	22.31	5.05	28.84	--
2 Mill Sources																						
2.1	Conveyor to Coarse Ore Stockpile	Mill Area	P	7,000,000	tons/yr	20,000	tons/day	Water sprays	N	1.40	8.00	0.28	1.60	--	--	--	--	--	--	--	--	7.00E-05
2.2	Apron Feeders	Mill Area	P	7,000,000	tons/yr	20,000	tons/day	Wet scrubber	N	0.70	4.00	0.14	0.80	--	--	--	--	--	--	--	--	3.50E-05
2.3	Conveyor Discharge to SAG Mill	Mill Area	P	7,000,000	tons/yr	20,000	tons/day	Wet scrubber	N	0.70	4.00	1.40E-01	0.80	--	--	--	--	--	--	--	--	3.50E-05
2.4	Concentrate Transfer	Mill Area	P	147,000	tons/yr	420	tons/day	Enclosed	N	2.94E-03	1.68E-02	5.88E-04	3.36E-03	--	--	--	--	--	--	--	--	1.29E-05
2.5	Concentrate Loading	Mill Area	P	147,000	tons/yr	420	tons/day	Enclosed	N	2.94E-03	1.68E-02	5.88E-04	3.36E-03	--	--	--	--	--	--	--	--	1.29E-05
2.6	Oversize Transfer to Hopper	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	N	0.07	0.40	1.40E-02	0.08	--	--	--	--	--	--	--	--	3.50E-06
2.7	Oversize Reclaim Belt Transfer	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	N	0.07	0.40	1.40E-02	0.08	--	--	--	--	--	--	--	--	3.50E-06
2.8	Oversize Crusher	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	N	0.35	2.00	0.07	0.40	--	--	--	--	--	--	--	--	1.75E-05
2.9	Oversize Screen	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	N	0.07	0.40	0.01	0.08	--	--	--	--	--	--	--	--	3.50E-06
2.10	Belt Transfer Back to SAG Mill	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	N	0.07	0.40	1.40E-02	0.08	--	--	--	--	--	--	--	--	3.50E-06
2.11	Coarse Ore Stockpile Wind Erosion	Mill Area	F	7,000,000	tons/yr	20,000	tons/day	Water	N	negligible	negligible	negligible	negligible	--	--	--	--	--	--	--	--	negligible
3 Haul Truck Activity																						
3.1	Haul Truck Travel	Forest Service Road 278	F	7,350	trips/yr	21	trips/day	Sealed Road	N	76.18	435.29	15.24	87.06	--	--	--	--	--	--	--	--	7.62E-04
4 Tailings Impoundment																						
4.1	Tailings Impoundment Wind Erosion	Tailings Area	F							10.48	59.91	2.10	11.98	--	--	--	--	--	--	--	--	5.24E-04
5 Surface Mobile Sources																						
5.1	Surface Mobile Sources		F					None	N	1.69	9.68	1.69	9.68	35.49	202.81	9.48	54.20	5.18	29.62	1.65	9.45	--
6 Miscellaneous																						
6.1	Laboratory Crusher		P	365	tons/yr	1	ton/day	None	N	0.03	0.16	0.01	0.03	--	--	--	--	--	--	--	--	negligible
	Total Point Source Emissions									5.92	34.32	2.81	16.61	1.59	13.73	0.33	4.38	0.00	0.00	0.09	1.15	3.16E-04
	Total Fugitive Source Emissions									90.70	518.27	21.35	122.02	100.05	571.70	109.10	623.41	9.12	52.09	6.70	38.29	1.29E-03

Table 2 - Preliminary HAP Inventory

Source ID Number	Description	General Location	Point or Fugitive	Annual Throughput	Units	Maximum Short-Term Throughput	Units	Controls	Annual As Emissions (tpy)	Annual Sb Emissions (tpy)	Annual Cr Emissions (tpy)	Annual Cd Emissions (tpy)
1	**Mine Sources**											
1.1	Blasting - Particulate	Underground	F	3,750	blasts/yr	14.71	blasts/day	Good blasting practices	8.00E-06	8.00E-07	1.20E-06	8.00E-07
	Blasting - Gaseous	Underground	F	4,775.5	tpy	13.64	tpd	Good blasting practices	--	--	--	--
1.2	Propane Heaters	Underground	P	347,900	gal/yr	2,304.00	gal/day	Good combustion practices	--	--	--	--
1.3	Primary Crushers	Underground	P	7,245,000	tons/yr	827.05	tons/hr	Venturi Scrubber	1.52E-04	1.52E-05	2.28E-05	1.52E-05
1.4	Coarse Ore Conveyor Transfers	Underground	P	7,000,000	tons/yr	799.09	tons/hr	Water Sprays	3.24E-04	3.24E-05	4.86E-05	3.24E-05
1.5	Underground Mobile Sources	Underground	F					None	--	--	--	--
2	**Mill Sources**											
2.1	Conveyor to Coarse Ore Stockpile	Mill Area	P	7,000,000	tons/yr	20,000	tons/day	Water sprays	2.80E-04	2.80E-05	4.20E-05	2.80E-05
2.2	Apron Feeders	Mill Area	P	7,000,000	tons/yr	20,000	tons/day	Wet scrubber	1.40E-04	1.40E-05	2.10E-05	1.40E-05
2.3	Conveyor Discharge to SAG Mill	Mill Area	P	7,000,000	tons/yr	20,000	tons/day	Wet scrubber	1.40E-04	1.40E-05	2.10E-05	1.40E-05
2.4	Concentrate Transfer	Mill Area	P	147,000	tons/yr	420	tons/day	Enclosed	5.88E-07	5.88E-08	8.82E-08	5.88E-08
2.5	Concentrate Loading	Mill Area	P	147,000	tons/yr	420	tons/day	Enclosed	5.88E-07	5.88E-08	8.82E-08	5.88E-08
2.6	Oversize Transfer to Hopper	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	1.40E-05	1.40E-06	2.10E-06	1.40E-06
2.7	Oversize Reclaim Belt Transfer	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	1.40E-05	1.40E-06	2.10E-06	1.40E-06
2.8	Oversize Crusher	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	7.00E-05	7.00E-06	1.05E-05	7.00E-06
2.9	Oversize Screen	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	1.40E-05	1.40E-06	2.10E-06	1.40E-06
2.10	Belt Transfer Back to SAG Mill	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	1.40E-05	1.40E-06	2.10E-06	1.40E-06
2.11	Coarse Ore Stockpile Wind Erosion	Mill Area	F	7,000,000	tons/yr	20,000	tons/day	Water	negligible	negligible	negligible	negligible
3	**Haul Truck Activity**											
3.1	Haul Truck Travel	Forest Service Road 278	F	7,350	trips/yr	21	trips/day	Sealed Road	1.52E-02	1.52E-03	2.29E-03	1.52E-03
4	**Tailings Impoundment**											
4.1	Tailings Impoundment Wind Erosion	Tailings Area	F						1.57E-03	2.10E-04	2.10E-04	2.10E-04
5	**Surface Mobile Sources**											
5.1	Surface Mobile Sources		F					None	--	--	--	--
6	**Miscellaneous**											
6.1	Laboratory Crusher		P	365	tons/yr	1	ton/day	None	--	--	--	--
	Total Point Source Emissions								1.16E-03	1.16E-04	1.74E-04	1.16E-04
	Total Fugitive Source Emissions								1.68E-02	1.73E-03	2.50E-03	1.73E-03

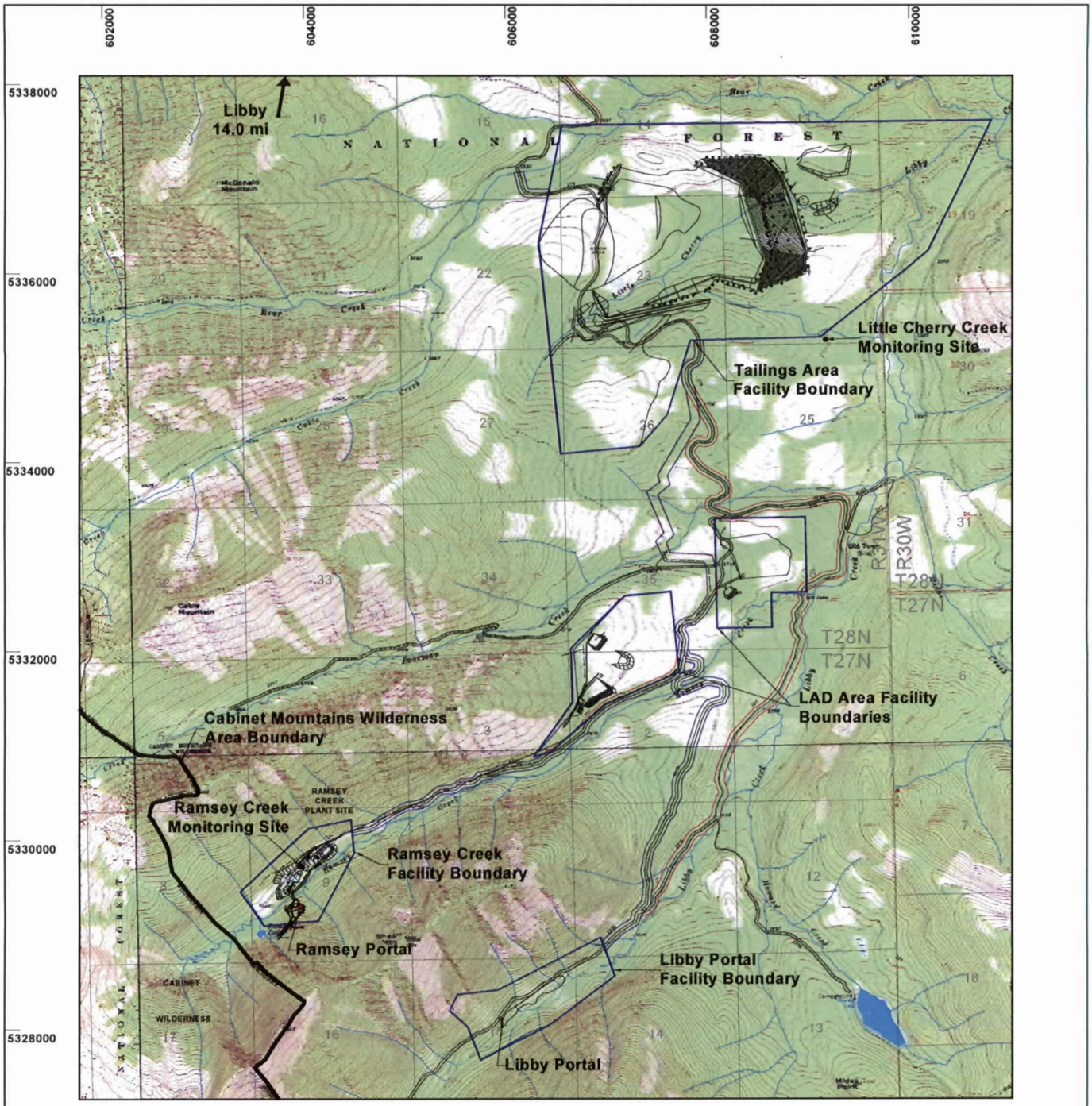
Table 3 - Modeled Source Parameters

Modeled Source ID	Emission Unit No.	Source Description	Source Type	Location (UTM Zone 12 NAD 27)		Elevation	Hs	T or • Ẏ	Vs or • Ż	Ds	Basis
				Easting	Northing	(m)	(m)	(K) or (m)	(m/s) or (m)	(m)	
RAMPORT	1.1-1.5	Ramsey Portal	Point	603962.7	5329301.3	1341.0	15.30	294.0	3.85	8.84	500,000 cfm, vertical release.
LIBPORT	1.1-1.5	Libby Portal	Point	605981.0	5328108.0	1233.0	6.00	294.0	0.01	0.01	Horizontal release, 18'x18' portal.
MSUREQP1	2.1-2.11, 5.1, 6.1	Mill Area Sources and Surface Mobile Equipment	Area	603779.0	5329448.0	1328.0	3.00	150.0	150.00	--	Emissions based on manufacturer's data, AP-42, and sulfur balances. 4 sources equally distributed over mill area, 4 equal 150m x 150m area sources, release height equal to 3m. Includes portion of mobile surface equipment operating in mill area and mill process sources.
MSUREQP2		Mill Area Sources and Surface Mobile Equipment	Area	603859.0	5329601.0	1328.0	3.00	150.0	150.00	--	
MSUREQP3		Mill Area Sources and Surface Mobile Equipment	Area	604011.0	5329733.0	1328.0	3.00	150.0	150.00	--	
MSUREQP4		Mill Area Sources and Surface Mobile Equipment	Area	604164.0	5329809.0	1328.0	3.00	150.0	150.00	--	
TAREA1	4.1, 5.1	Tailings Dam Wind Erosion and Mobile Surface Equipment	Area	607108.7	5336185.0	1097.3	0.10/3.00	770.9	770.90	--	Emissions based on manufacturer's data, AP-42, and sulfur balances. 2 area sources distributed over tailings area, each 770.9m x 770.9m, release height equal to 3m for mobile equipment, 0.1m for wind erosion. Includes portion of mobile surface equipment operating at the mill area and wind erosion from the tailings dam.
TAREA2		Tailings Dam Wind Erosion and Mobile Surface Equipment	Area	607975.7	5336187.0	1097.3	0.10/3.00	770.9	770.90	--	
LAD	5.1	Mobile Surface Equipment at LAD	Area	606869.0	5331613.3	1219.0	3.00	250.0	250.00	--	Emissions based on manufacturer's data, AP-42, and sulfur balances. 250m x 250m area source, release height equal to 3m. Includes portion of mobile surface equipment operating at the LAD area.
LIBLOADR	5.1	Loader at Libby Portal Area	Area	605985.5	5328100.5	1233.0	3.00	15.0	15.00	--	Emissions based on manufacturer's data, AP-42, and sulfur balances. 15m x 15m area source, release height equal to 3m. Includes a loader operating at the Libby Portal area.

Table 4 - Ambient Background Concentrations

Pollutant	Averaging Period	Background Concentration ($\mu g/m^3$)	Data Source
PM_{10}	Annual	14	1988-1989 Montanore Mine
	24-Hour	35	1988-1989 Montanore Mine
$PM_{2.5}$	Annual	3.5	Cabinet Mtns Wilderness IMPROVE
	24-Hour	10.4	Cabinet Mtns Wilderness IMPROVE
NO_2	Annual	6	MDEQ
	1-Hour	75	MDEQ
SO_2	Annual	3	MDEQ
	24-Hour	11	MDEQ
	3-Hour	26	MDEQ
	1-Hour	35	MDEQ
Lead	Annual	0.006	1988-1989 Montanore Mine

Note: Background values approved by MDEQ in letter communication dated July 12, 2005.



Graphic Scale
0 500 1000 1500 2000 3000
Coordinates in UTM (meters) NAD27

Note: No schools are located within 3,000 feet of any facility boundary.
North arrow represents true north.

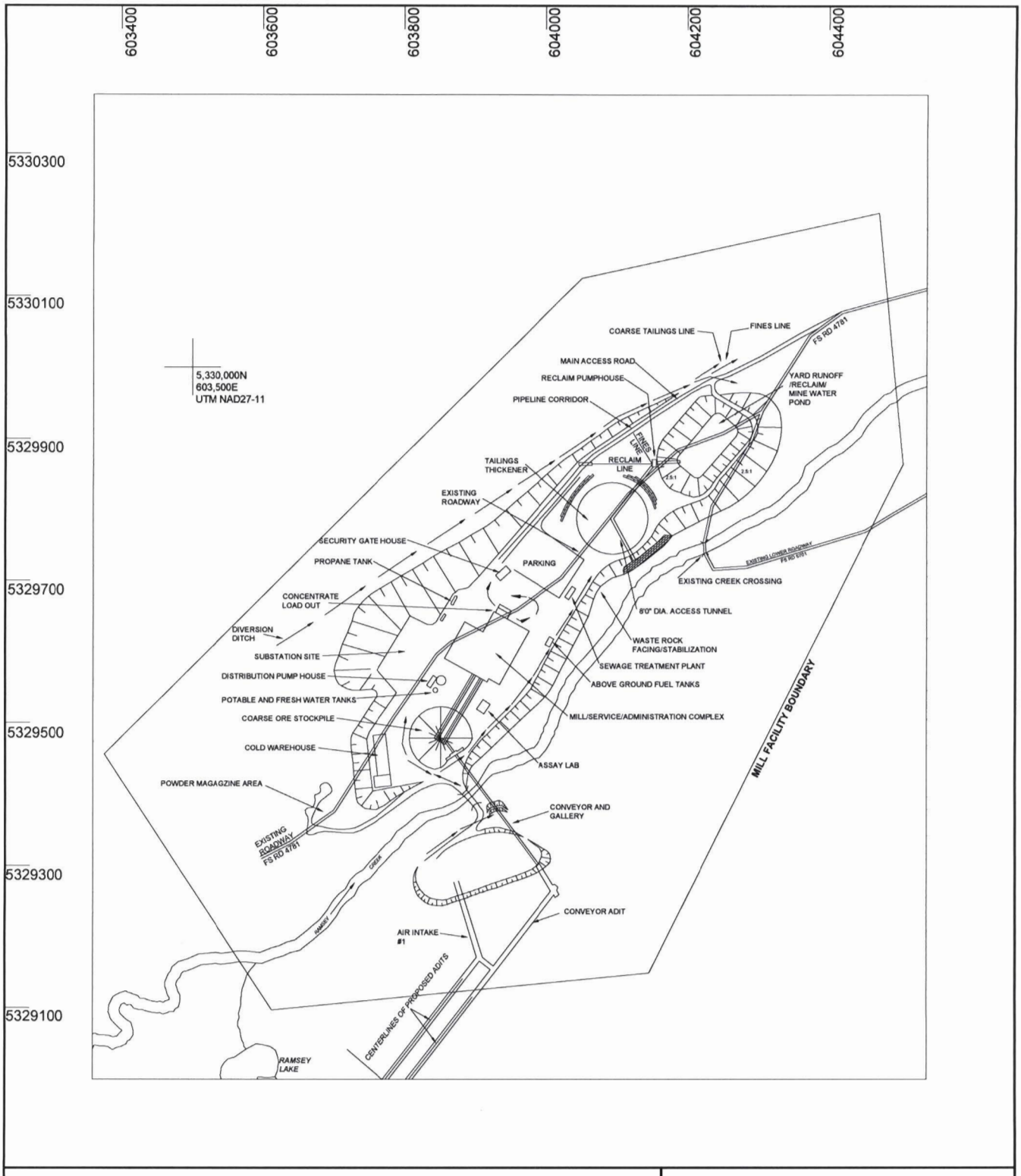
FIGURE 1

MONTANORE MINE
GENERAL FACILITY LOCATIONS

Project: 46706-000-00000
Date: 9/19/2005
Rev: 0

TRC

Figure based on "Draft Figure", Jasper Geographics, March, 2005.



N

Graphic Scale

0 125 250 500

Coordinates in UTM (meters) NAD27

FIGURE 2

MONTANORE MINE
MILL FACILITY

Project: 46706-000-00000

Date: 9/21/2005

Rev: 0

TRC

Figure based on "Figure 17", Jasper Geographics, April, 2005.

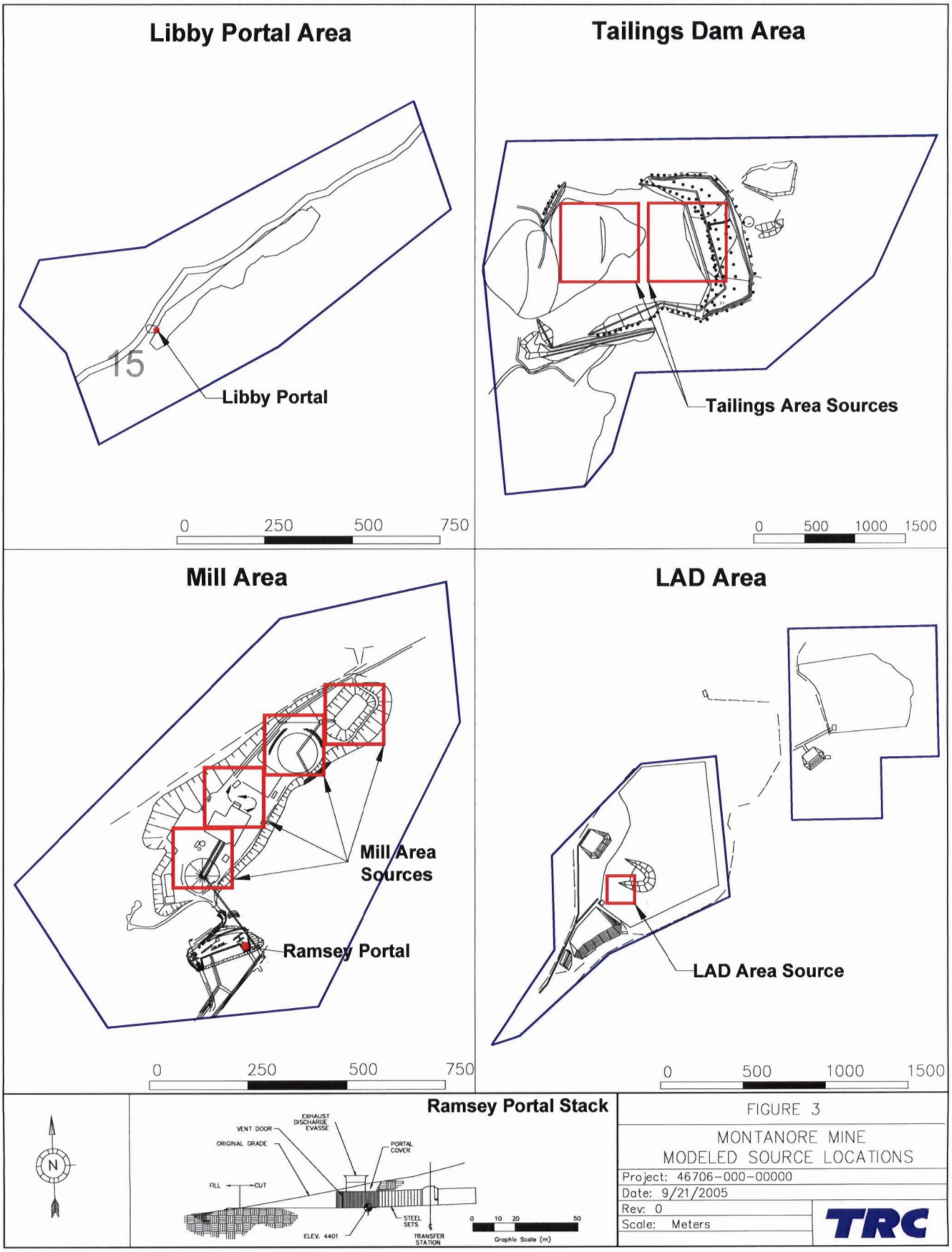
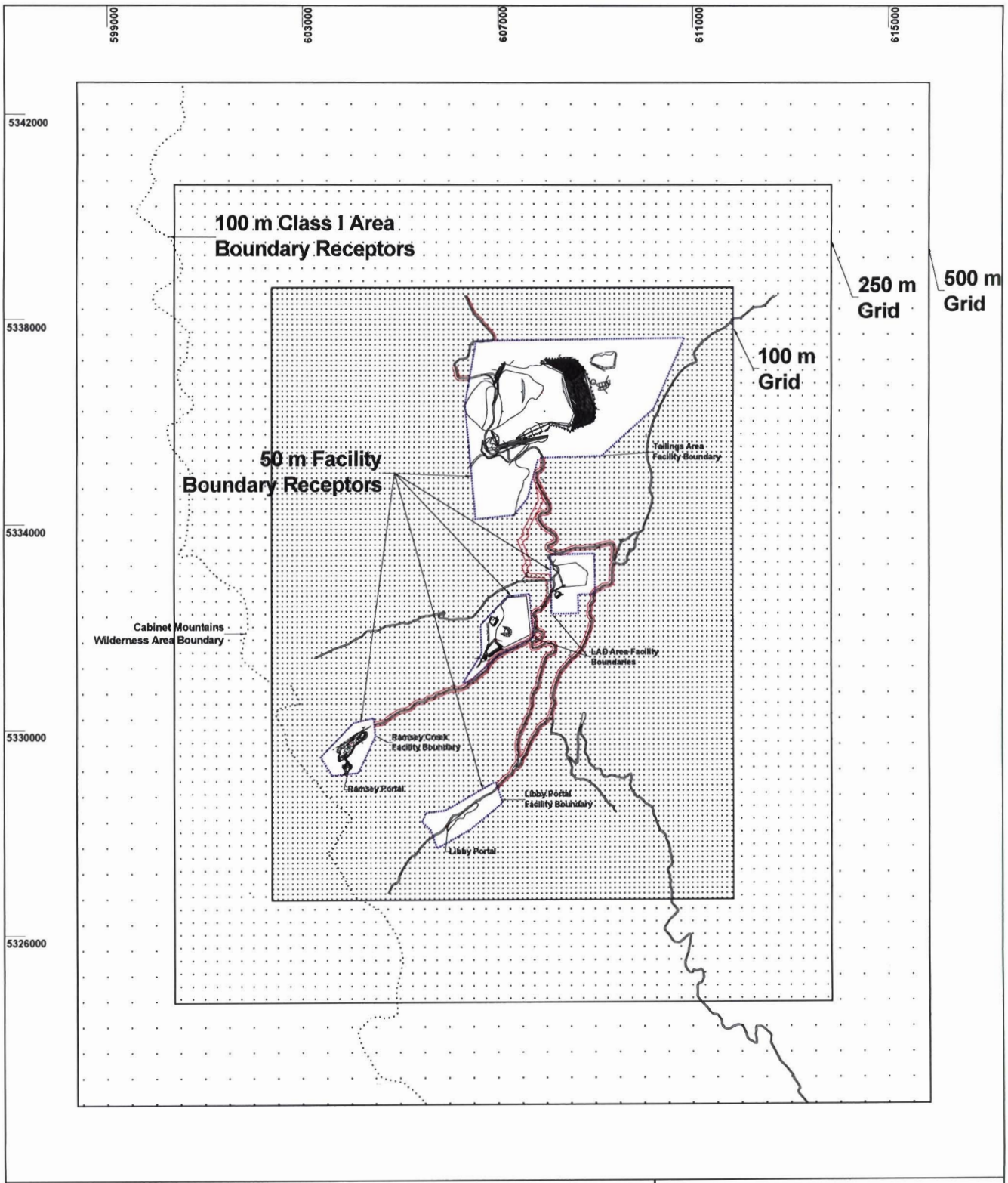


FIGURE 3

MONTANORE MINE
MODELED SOURCE LOCATIONS

Project: 46706-000-00000
Date: 9/21/2005
Rev: 0
Scale: Meters

TRC



N

Graphic Scale

0 1000 2000 3000 4000 6000

Coordinates in UTM (meters) NAD27

Note: North arrow represents true north.

FIGURE 4

MONTANORE MINE

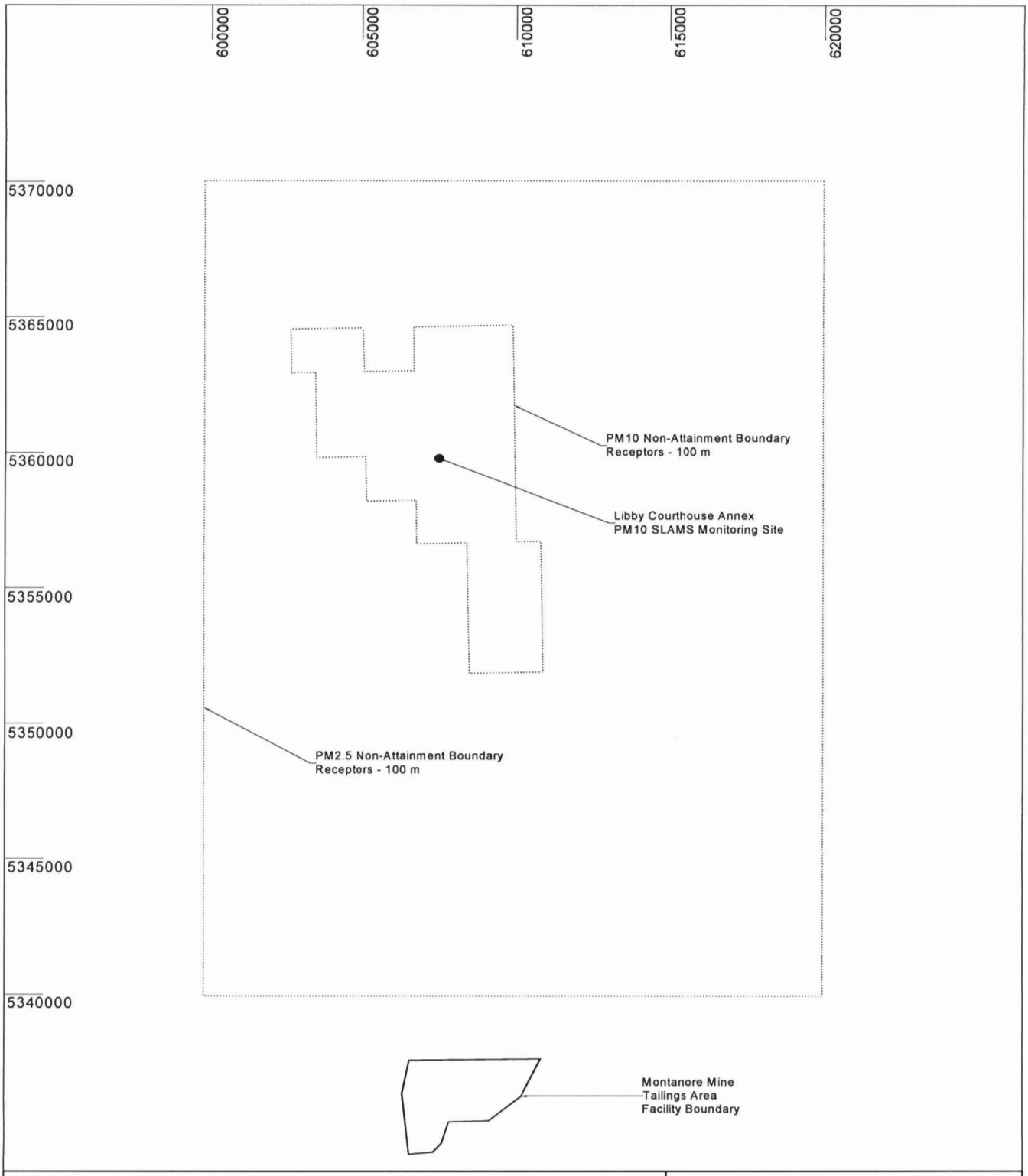
COMPLIANCE/RISK ASSESSMENT MODEL RECEPTORS

Project: 46706-000-00000

Date: 9/21/2005

Rev: 0

TRC



N

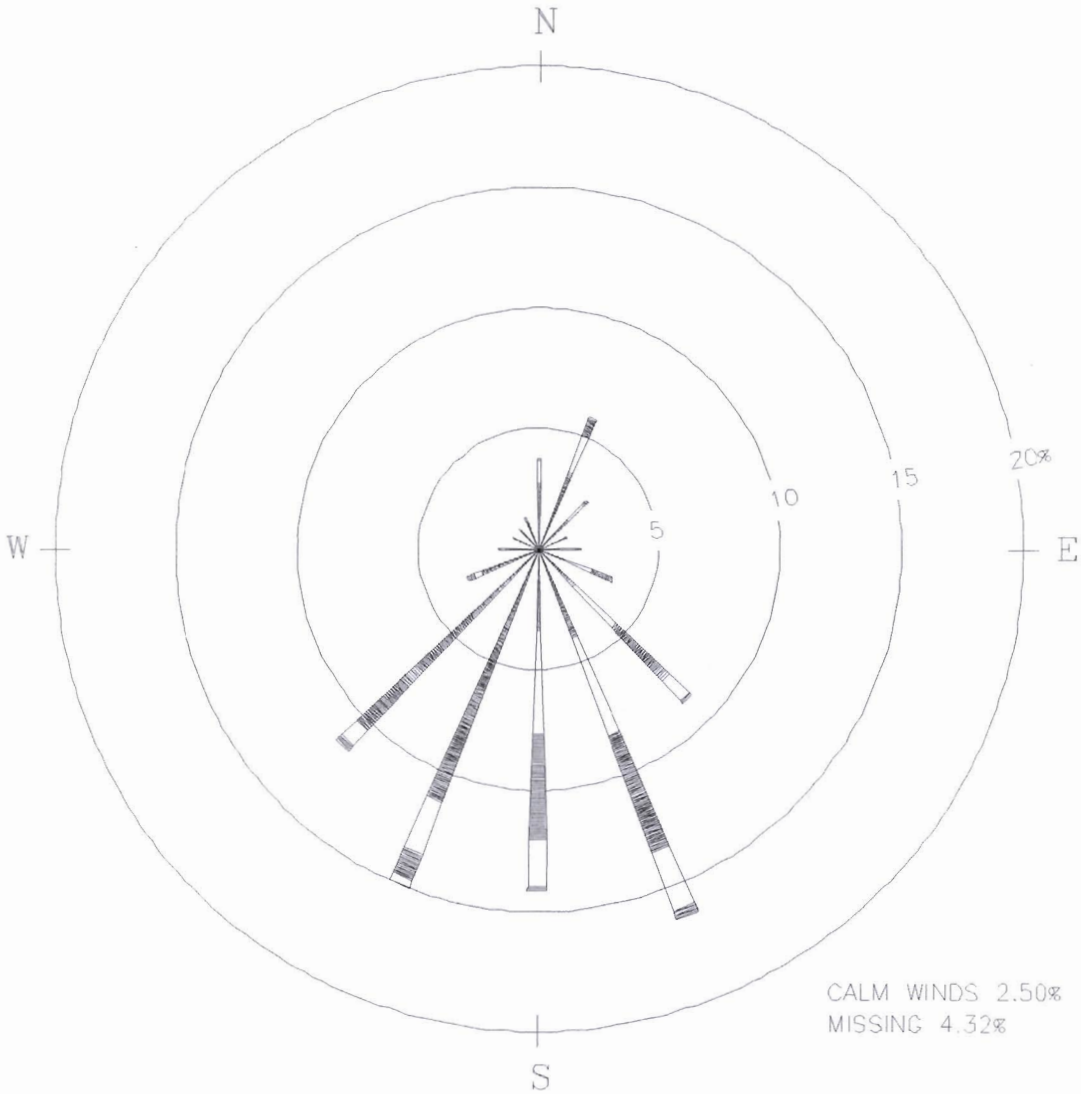
Graphic Scale
0 1000 2000 3000 4000 6000
Coordinates in UTM (meters) NAD27

FIGURE 5

MONTANORE MINE
NONATTAINMENT AREA MODEL RECEPTORS

Project: 46706-000-00000
Date: 9/21/2005
Rev: 0

TRC



WIND SPEED CLASS BOUNDARIES
(METERS/SECOND)

FIGURE 6
WINDROSE
RAMSEY CREEK SITE
JULY 1988–JUNE 1989

NOTES:
DIAGRAM OF THE FREQUENCY OF OCCURRENCE OF EACH WIND DIRECTION. WIND DIRECTION IS THE DIRECTION FROM WHICH THE WIND IS BLOWING. EXAMPLE – WIND IS BLOWING FROM THE NORTH 3.7 PERCENT OF THE TIME.

BEE–LINE
SOFTWARE

CD-ROM

Meteorological Data File
BPIP Input and Output Files

TRC

Customer-Focused Solutions

December 12, 2005

Mr. Eric Thunstrom
Montana Department of Environmental Quality
PO Box 200901
Helena, MT 59620-0901

Subj: Mines Management, Inc. Montanore Mine Project
Minor Source Permit Application
Modeling Analysis Protocol

Dear Eric,

TRC received the memorandum from Montana Department of Environmental Quality Air Resources Management Bureau (MDEQ-ARMB) dated October 5, 2005 regarding review of the Mines Management, Inc. Montanore Mine Project modeling analysis protocol letter dated September 27, 2005. Thank you for your review and comment on the modeling protocol. This letter acknowledges receipt of the MDEQ-ARMB review memorandum and briefly discusses the topics presented therein. This letter also provides a written record of analysis protocol developed for several other modeling issues discussed verbally between TRC and MDEQ-ARMB in recent weeks.

MDEQ-ARMB October 5, 2005 Memorandum Issues

Dispersion modeling topics presented by MDEQ-ARMB in their October 5 memorandum are responded to below. Visibility and $PM_{2.5}$ nonattainment area modeling are reserved for discussion in the next section.

Emissions Inventory

A draft air emissions inventory for the mine production phase was provided to MDEQ-ARMB on October 6, 2005. The inventory was provided for preliminary review by permit engineers and to hasten review of the full application document upon submittal. The draft emissions inventory and the permit application document will answer questions regarding deposition calculations.

At MDEQ-ARMB request, additional data, including specifications, schedule, and ambient analysis will be provided for the diesel-powered emergency generator to be located on-site during the production phase. The generator would be included in dispersion modeling at the maximum operating schedule which is anticipated to be permitted by Mines Management. Visibility impacts also will be assessed for the generator stack.

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Tel. (307) 742-3843 • Fax (307) 745-8317

Additional Receptors

TRC will place additional receptors at prominent terrain features within 10 km from the mine portals, and place discrete receptors at sensitive alpine lakes as identified by MDEQ-ARMB.

Meteorological Data Processing

The election of MSGPRO will be discussed in the application document.

Source Parameters

The Libby Portal release characteristics will be modified to reflect true volume flowrate.

Downwash for Portal Exhaust

MDEQ-ARMB would like a discussion of the potential impacts of downwash effects on the Ramsey portal from high terrain nearby, and how it might affect model results. An analysis of the potential effects of terrain-induced downwash will be included in the application document.

Additional Proposed Modeling Methodologies

Additional details on modeling methodology that were not part of the September 27 protocol letter have been discussed with MDEQ-ARMB, and are presented below.

$PM_{2.5}$ Nonattainment Area Modeling

MDEQ-ARMB expressed interest in modeling the potential contribution of nitrate and sulfate species to total $PM_{2.5}$ impacts at the $PM_{2.5}$ nonattainment area boundary. Specifically, the impact on $PM_{2.5}$ from sulfate and nitrate emitted from the portal (from conversion of SO_2 and NOx emissions from underground sources) was requested by MDEQ-ARMB.

TRC is proposing the use of CALPUFF in screening mode consistent with IWAQM guidance and using CALPUFF screening model options currently recommended by Earth Tech, Inc., the developers of CALPUFF (guidance dated January 2002, see Attachment A). All source and receptor input parameters would be identical to those utilized in the ISCST3 regulatory compliance modeling. The CALPUFF screening tool would calculate total $PM_{2.5}$ and would include use of the MESOPUFF chemistry algorithm to calculate conversion of SO_2 and NOx to sulfate and nitrate, respectively, based on environmental factors.

Visibility Modeling

MDEQ-ARMB discussed their desired visibility modeling methodology in phone conversations with TRC on October 13 and November 21.

MDEQ-ARMB indicated that although the Montanore Mine is a minor source, and visibility impacts would not be considered in the permit decision, the impacts would be under scrutiny in the EIS and therefore Mines Management should address them fully. MDEQ-ARMB also indicated that acceptable impacts would be consistent with those acceptable from a major source. TRC explained that the VISCREEN Levels 1 and 2 analyses exceeded visibility thresholds and proposed a PLUVUE II model run with one worst-case viewpoint and worst-case meteorology, explaining that this worst-case analysis was anticipated to show impacts above thresholds under E and F stability, but they could be explained based on terrain and geometry of the sun angle during periods which E and F stability occurred. MDEQ-ARMB requested instead to see a PLUVUE II analysis that utilized the Ramsey hourly meteorology, and was consistent with FLM guidance for major sources. MDEQ-ARMB suggested that pollutant background be set to zero for pollutants input to PLUVUE II.

On November 21, TRC spoke with MDEQ-ARMB regarding several problems with the PLUVUE II runs which required MDEQ-ARMB input.

The first problem was found to be if input background values for NOx, NO_2 and SO_2 were set to zero (as suggested by MDEQ-ARMB during the October 13 conference call) the PLUVUE model chemistry algorithm produced numerical errors leading to unrealistic plume perceptibility parameters for certain meteorological conditions, especially for cold ambient temperatures (< 30 degs F). Several examples were sent to MDEQ-ARMB on November 21 which documented these numerical errors and their occurrence. In TRC's November 21 phone conversation with MDEQ-ARMB, MDEQ-ARMB requested that alternative background values be selected from other regional sites, such as CASTNET. Proposed background concentrations for NOx and NO_2 are 0.449 $\mu g/m^3$ (0.00018 ppm), an annual background NO_3 concentration at Glacier NP CASTNET site for the most recent year available (2003) and used as a conservative (low) estimate of NO_2. The proposed background concentration for SO_2 is 0.447 $\mu g/m^3$ (0.00017 ppm), an annual background SO_2 concentration at Glacier NP CASTNET site for the most recent year available (2003). Both CASTNET datasets can be accessed at http://www.epa.gov /castnet.html, and from the menu, select: *Annual estimates of concentration, deposition velocities and fluxes; aggregated from quarterly estimates in the VELQR table* [filename: velan.zip, within the raw data file "velan.csv" search for Glacier NP site (GLR468)]. Proposed background coarse PM is 6.8 $\mu g/m^3$, an annual background value from Cabinet Mountains IMPROVE site for 2003 (http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm, filename daily_budgets_24Jan05.csv). Please refer to the data sources listed above to obtain further information regarding the background values used.

The second issue regarding the PLUVUE II model is that when the stack temperature is less than or, in some cases, equal to the ambient temperature, the PLUVUE code crashes, which TRC has determined is a problem with the plume rise algorithm. Therefore, TRC proposed that when the ambient temperature is greater than or equal to the stack temperature, the stack temperature would be set to ambient temperature plus 0.1 degrees F.

Overall, the FLAG-recommended PLUVUE II model is used with model default switch settings, seasonal relative humidity data applicable to the Cabinet Mountain Wilderness Area obtained from regional haze rule guidance and background seasonal standard visual range, for the Cabinet Mountains Wilderness Area, from FLAG, as requested by MDEQ-ARMB. A single viewpoint for each analyzed source was selected by determining the location with the most viewing angles that an observer could see a plume generated by each source. On-site meteorological data collected at the Ramsey Portal site were utilized. As stated above, background values were obtained from regional CASTNET and IMPROVE sites.

TRC believes that the visibility modeling methodology proposed above provides an extensive impact analysis for the Montanore Mine which, as a minor source, emits pollutants at levels that under MDEQ permitting regulations would not be explicitly required to conduct a visibility analysis. With the understanding that this analysis is not a permit requirement and will not be considered in permit review and approval and, rather, will be utilized to illustrate potential visibility impacts for the Supplemental Environmental Impact Statement, TRC requests formal approval of the proposed protocol as presented above.

Thank you for you review and comment on the modeling protocol and continued input on modeling-related issues for the Montanore Mine project. A paper copy of this letter will follow via regular mail. Please contact me at (308) 764-2363 if you have any questions or would like to discuss these issues further. We look forward to receiving an indication of your approval of the visibility and nonattainment modeling protocols presented in this letter.

Sincerely,

TRC ENVIRONMENTAL CORPORATION

Susan Connell

Susan J. Connell
Air Quality Scientist

cc: E. Klepfer
file
Attachment

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Tel. (307) 742-3843 • Fax (307) 745-8317

ATTACHMENT A
CALPUFF SCREENING GUIDANCE

APPENDIX C

AIR EMISSIONS INVENTORY

Source ID Number	Description	General Location	Point, Fugitive or Mobile	Annual Throughput	Units	Maximum Short-Term Throughput	Units	Controls	Accounted for Deposition?	Annual PM_{10} Emissions (tpy)	24-Hour PM_{10} Emissions (lb/day)	Annual $PM_{2.5}$ Emissions (tpy)	24-Hour $PM_{2.5}$ Emissions (lb/day)	Annual NO_x Emissions (tpy)	24-Hour NO_x Emissions (lb/day)	Annual CO Emissions (tpy)	24-Hour CO Emissions (lb/day)	Annual SO_2 Emissions (tpy)	24-Hour SO_2 Emissions (lb/day)	Annual VOC Emissions (tpy)	24-Hour VOC Emissions (lb/day)	Annual Lead Emissions (tpy)	Annual As Emissions (tpy)	Annual Sb Emissions (tpy)	Annual Cr Emissions (tpy)	Annual Cd Emissions (tpy)
1.0 Mine Sources																										
1.1	Blasting - Particulate	Underground	F	3,750	blasts/yr	14.71	blasts/day	Good blasting practices	Y	0.40	2.31	0.02	0.13	--	--	--	--	--	--	--	--	2.02E-05	8.08E-05	8.08E-06	1.21E-05	8.08E-06
	Blasting - Gaseous	Underground	F	4,775.5	tpy	13.64	tpd	Good blasting practices	N	--	--	--	--	1.33	7.57	64.66	369.50	0.14	0.82	--	--	--				
1.2	Propane Heaters	Underground	P	347,900	gal/yr	2,304.00	gal/day	Good combustion practices	N	0.07	0.92	0.07	0.92	2.44	32.26	0.33	4.38	2.78E-03	3.69E-02	0.09	1.15	--	--	--	--	--
1.3	Primary Crushers	Underground	P	7,245,000	tons/yr	827.05	tons/hr	Water Sprays	Y	3.26	18.63	0.65	3.73	--	--	--	--	--	--	--	--	1.83E-04	6.52E-04	6.52E-05	9.78E-05	6.52E-05
1.4	Coarse Ore Conveyor Transfers	Underground	P	7,000,000	tons/yr	799.09	tons/hr	Water Sprays	Y	7.00	40.00	1.40	8.00	--	--	--	--	--	--	--	--	3.50E-04	1.40E-03	1.40E-04	2.10E-04	1.40E-04
1.5	Underground Mobile Sources	Underground	M	See Mobile Source Sheets				None	N	2.40	13.17	2.40	13.17	102.19	559.96	36.45	199.72	4.07	22.31	5.26	28.84	--	--	--	--	--
2.0 Mill Sources																										
2.1	Conveyor to Coarse Ore Stockpile	Mill Area	P	7,000,000	tons/yr	20,000	tons/day	Water sprays	N	1.40	8.00	0.28	1.60	--	--	--	--	--	--	--	--	7.00E-05	2.80E-04	2.80E-05	4.20E-05	2.80E-05
2.2	Apron Feeders	Mill Area	P	7,000,000	tons/yr	20,000	tons/day	Wet scrubber	N	0.70	4.00	0.14	0.80	--	--	--	--	--	--	--	--	3.50E-05	1.40E-04	1.40E-05	2.10E-05	1.40E-05
2.3	Conveyor Discharge to SAG Mill	Mill Area	P	7,000,000	tons/yr	20,000	tons/day	Wet scrubber	N	0.70	4.00	0.14	0.80	--	--	--	--	--	--	--	--	3.50E-05	1.40E-04	1.40E-05	2.10E-05	1.40E-05
2.4	Concentrate Transfer	Mill Area	P	147,000	tons/yr	420	tons/day	Enclosed	N	2.94E-03	1.68E-02	5.88E-04	3.36E-03	--	--	--	--	--	--	--	--	1.29E-05	5.88E-07	5.88E-08	8.82E-08	5.88E-08
2.5	Concentrate Loading	Mill Area	P	147,000	tons/yr	420	tons/day	Enclosed	N	2.94E-03	1.68E-02	5.88E-04	3.36E-03	--	--	--	--	--	--	--	--	1.29E-05	5.88E-07	5.88E-08	8.82E-08	5.88E-08
2.6	Oversize Transfer to Hopper	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	N	0.07	0.40	0.01	0.08	--	--	--	--	--	--	--	--	3.50E-06	1.40E-05	1.40E-06	2.10E-06	1.40E-06
2.7	Oversize Reclaim Belt Transfer	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	N	0.07	0.40	0.01	0.08	--	--	--	--	--	--	--	--	3.50E-06	1.40E-05	1.40E-06	2.10E-06	1.40E-06
2.8	Oversize Crusher	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	N	0.35	2.00	0.07	0.40	--	--	--	--	--	--	--	--	1.75E-05	7.00E-05	7.00E-06	1.05E-05	7.00E-06
2.9	Oversize Screen	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	N	0.07	0.40	0.01	0.08	--	--	--	--	--	--	--	--	3.50E-06	1.40E-05	1.40E-06	2.10E-06	1.40E-06
2.10	Belt Transfer Back to SAG Mill	Mill Area	P	350,000	tons/yr	1,000	tons/day	Water Sprays	N	0.07	0.40	0.01	0.08	--	--	--	--	--	--	--	--	3.50E-06	1.40E-05	1.40E-06	2.10E-06	1.40E-06
2.11	Coarse Ore Stockpile Wind Erosion	Mill Area	F	7,000,000	tons/yr	20,000	tons/day	Water	N	negligible	negligible	negligible	negligible	--	--	--	--	--	--	--	--	negligible	negligible	negligible	negligible	negligible
2.12	Emergency Generator	Mill Area/Substation	P					Low S Diesel	N	2.57E-03	7.72	2.57E-03	7.72	0.18	549.25	8.87E-03	26.60	4.66E-03	13.99	5.44E-03	16.31	--	--	--	--	--
3.0 Haul Truck Activity																										
3.1	Haul Truck Travel	Forest Service Road 276	F	7,350	trips/yr	21	trips/day	Sealed Road	N	76.18	435.29	15.24	87.06	--	--	--	--	--	--	--	--	7.62E-04	1.52E-02	1.52E-03	2.29E-03	1.52E-03
4.0 Tailings Impoundment																										
4.1	Tailings Impoundment Wind Erosion	Tailings Area	F							negligible	negligible	negligible	negligible	--	--	--	--	--	--	--	--	negligible	negligible	negligible	negligible	negligible
5.0 Surface Mobile Sources																										
5.1	Surface Mobile Sources		M	See Mobile Source Sheets				None	N	1.77	9.68	1.77	9.68	37.01	202.81	9.89	54.20	5.41	29.62	1.73	9.45	--	--	--	--	--
6.0 Miscellaneous																										
6.1	Laboratory Crusher		P	365	tons/yr	1	ton/day	None	N	0.03	0.16	0.01	0.03	--	--	--	--	--	--	--	--	negligible	negligible	negligible	negligible	negligible
	Total Point Source Emissions									13.80	87.07	2.82	24.33	2.82	581.50	0.34	30.98	0.01	14.03	0.09	17.46	7.10E-04	2.74E-03	2.74E-04	4.11E-04	2.74E-04
	Total Fugitive Source Emissions									76.58	437.60	15.26	87.19	1.33	7.57	64.66	369.50	0.14	0.82	0.00	0.00	7.62E-04	1.53E-02	1.53E-03	2.30E-03	1.53E-03
	Total Mobile Source Emissions									4.17	22.85	4.17	22.85	139.20	762.77	46.34	253.91	9.48	51.93	6.99	38.29	0.00	0.00	0.00	0.00	0.00

Montanore Mine
Blasting - Particulate Emissions
Source Number: 1.1

Activity	Area Blasted	tons/blast	tons/day	Blasts per Year	Blasts per Day	Annual PM_{10} Emissions	Max 24-hr PM_{10} Emissions	Annual $PM_{2.5}$ Emissions	Max 24-hr $PM_{2.5}$ Emissions	Annual Lead Emissions
	(ft^2)					(tpy)	(lb/day)	(tpy)	(lb/day)	(tpy)
Topslice	800	933.33	10,000.00	3,750	10.71	0.31	1.76	0.02	0.10	1.54E-05
Bench	800	5,000.00	10,000.00	700	2.00	0.06	0.33	3.33E-03	0.02	2.88E-06
Development	600	350.00	700.00	700	2.00	0.04	0.21	2.16E-03	0.01	1.87E-06
TOTAL		6,283.33	20,700.00	5,150	14.71	0.40	2.31	0.02	0.13	2.02E-05
			7,245,000	tons/yr						

Notes:
[1] AP-42 (EPA, 1998), Table 11.9-1, "Emission Factor Equations for Uncontrolled Open Dust Sources at Western Surface Coal Mines."

Montanore Mine
Blasting - Gaseous Emissions
Source Number: 1.1

Explosive	Pollutant	Annual Explosive Usage[2] (tpy)	Max Daily Explosive Usage (tons/day)	Emission Factor[1] (lb/ton)	Annual Emissions (tpy)	Max 24 hr Emissions (lb/day)
RU Emulsion[1]	NO_x	4,770.50	13.63	0.50	1.19	6.82
	CO	4,770.50	13.63	27.00	64.40	368.01
	SO_2	4,770.50	13.63	0.06	0.14	0.80
High Explosive[3]	NO_x	5	0.01	53	0.13	0.76
	CO	5	0.01	104	0.26	1.49
	SO_2	5	0.01	1	0.00	0.01

Note:
[1] Dyno Nobel North America, "Emission Factors for Dyno RU Emulsion", August 26, 2005

[2] Powder factors =

Powder factors used for Montanore Mine Plan:			tons/day	tons/shot	shots/day	shot dimensions length	width	height	ft3	tons/shot	shots/day
Benching/slashing	0.80	lb/ton	10,000			75	40	20	60,000	5,000.00	2.00
Top heading	1.80	lb/ton	10,000			14	40	20	11,200	933.33	10.71
Development	1.80	lb/ton	700			7	40	15	4,200	350.00	2.00
total	1.32	lb/ton	20,700								14.71
total powder/day	tons		13.63	tons	4,770.50	tons/yr	powder - emulsion (100%)				
total powder/day	lbs		27,260	lbs	5.00	tons/yr	dynamite for secondary blasting of boulders				
					4,775.50	tons/yr	13.64	tons/day			

Listed below is typical powder consumption in hard rock.
Shaft Sinking – 2.5 Lb./short ton broken
Drifting – 1.8 Lb./short ton broken
Raising – 1.5 Lb./short ton broken
Slashing – 0.8 Lb./short ton broken
Shrink Stope – 0.5 Lb./short ton broken
O/H Cut and Fill – 0.5 Lb./short ton broken
Bulk Mining – 0.4 Lb./short ton broken
Block Cave u/c – 0.1 Lb./short ton to be caved
Open Pit Cut – 0.9 Lb./short ton broken
Open Pit Bench – 0.6 Lb./short ton broken

[3] AP-42 (EPA, 1980), Table 13.3-1, "Emission Factors for Detonation Explosives."
Emission factors selected for high explosives are those for gelatin dynamite with a range of 20-100% nitroglycerine.

Montanore Mine
Propane Combustion (Heaters)
Source Number: 1.2

Pollutant	Emission Factor[1]	Propane Use	Annual Emissions	Max. 24-Hour Emissions
	(lb/10^3 gal)	(10^3 gal/yr)	(tpy)	(lb/day)
PM_{10}	0.4	347.9	0.07	0.92
$PM_{2.5}$	0.4	347.9	0.07	0.92
NO_x	14.0	347.9	2.44	32.26
CO	1.9	347.9	0.33	4.38
VOC	0.5	347.9	0.09	1.15
SO_2[2]	0.016	347.9	2.78E-03	0.04

Notes:
[1] AP-42 (EPA, 1996), Table 1.5-1, "Emission Factors for LPG Combustion."
[2] Sulfur content assumed 0.16 grains/100 ft^3; see footnote "e" of Table 1.5-1, EPA, 1996.

Montanore Mine
Primary Crushers
Source Number: 1.3

Annual Throughput (tpy)	Maximum Daily Throughput[1] (tons/day)	Water Spray Controls (%)	PM_{10} Emission Factor[2] (lb/ton)	Annual PM_{10} Emissions (tpy)	Maximum 24-hr PM_{10} Emissions (lb/day)	Annual $PM_{2.5}$ Emissions (tpy)	Maximum 24-hr $PM_{2.5}$ Emissions (lb/day)	Annual Lead Emissions (tpy)
7,245,000	20,700	90	0.009	3.26	18.63	0.65	3.73	1.63E-04

Note:
[1] 1300 tph of ore and waste rock
[2] AP-42 (EPA, 1982), Section 11.24, "Metallic Minerals Processing."

Montanore Mine
Ramsey Adit Coarse Ore Conveyor Transfers
Source Number: 1.4

Ore Handling Activity	Annual Throughput	24-Hour Throughput	# of Conveyor Transfers	Moisture Content	Emission Control Efficiency[1]	PM_{10} Emission Factor[2]	Annual PM_{10} Emissions	Max 24-hr PM_{10} Emissions	Annual $PM_{2.5}$ Emissions	Max 24-hr $PM_{2.5}$ Emissions	Annual Lead Emissions
	(tpy)	(tons/day)		(%)	(%)	(lb/ton)	(tpy)	(lbs/day)	(tpy)	(lbs/day)	(tpy)
Underground Coarse Ore Conveyor Transfers	7,000,000	20,000	5	5	90	0.00400	7.00	40.00	1.40	8.00	3.50E-04

Notes:
[1] Water spray control = 90%
[2] AP-42 (EPA, 1982), Section 11.24-2, "Metallic Mibneral Processing."

Montanore Mine
Mill Sources
Source Numbers: 2.1 through 2.11

Source Number	Ore Handling Activity	Annual Throughput (tpy)	24-Hour Throughput (tons/day)	Moisture Content (%)	Emission Control	Emission Control Efficiency[2] (%)	PM_{10} Emission Factor[1] (lb/ton)	Annual PM_{10} Emissions (tpy)	Max 24-hr PM_{10} Emissions (lbs/day)	Annual $PM_{2.5}$ Emissions (tpy)	Max 24-hr $PM_{2.5}$ Emissions (lbs/day)	Annual Lead Emissions (tpy)
2.1	Conveyor to Coarse Ore Stockpile	7,000,000	20,000	5	water spray	90	0.00400	1.40	8.00	0.28	1.60	7.00E-05
2.2	Apron Feeders	7,000,000	20,000	5	wet scrubber	95	0.00400	0.70	4.00	0.14	0.80	3.50E-05
2.3	Conveyor Discharge to SAG Mill	7,000,000	20,000	5	wet scrubber	95	0.00400	0.70	4.00	0.14	0.80	3.50E-05
2.4	Concentrate Transfer	147,000	420	8	enclosure	99	0.00400	2.94E-03	0.02	5.88E-04	3.36E-03	1.29E-05
2.5	Concentrate Loading	147,000	420	8	enclosure	99	0.00400	2.94E-03	0.02	5.88E-04	3.36E-03	1.29E-05
2.6	Oversize Transfer to Hopper	350,000	1,000	5	water spray	90	0.00400	0.07	0.40	0.01	0.08	3.50E-06
2.7	Oversize Reclaim Belt Transfer	350,000	1,000	5	water spray	90	0.00400	0.07	0.40	0.01	0.08	3.50E-06
2.8	Oversize Crusher	350,000	1,000	5	water spray	90	0.02000	0.35	2.00	0.07	0.40	1.75E-05
2.9	Oversize Screen	350,000	1,000	5	water spray	90	0.00400	0.07	0.40	0.01	0.08	3.50E-06
2.10	Belt Transfer Back to SAG Mill	350,000	1,000	5	water spray	90	0.00400	0.07	0.40	0.01	0.08	3.50E-06

Notes:
[1] AP-42 (EPA, 1995), Section 13.2.4, "Aggregate Handling and Storage Piles." and 11.24 - "Metallic Minerals Processing".
[2] Water spray control = 90% wet scrubber control = 95%, enclosure control = 99%.

Montanore Mine
Emergency Generator
Source Number: 2.12

Engine Size: 1.0 MW (1622 hp)
Annual Operating Rate: 4 hours/quarter
Maximum Daily Operating Rate: 4 hours/day

Pollutant	Emission Factor[1]	Engine Horsepower	Maximum Hourly Emissions	Maximum Daily Emissions[2]	Annual Emissions[3]
	(g/hp-hr)	(hp)	(lb/hour)	(lb/day)	(tpy)
NO_x	6.4	1622	22.89	91.54	0.1831
CO	0.31	1622	1.11	4.43	0.0089
VOCs	0.19	1622	0.68	2.72	0.0054
SO_2[4]	0.163	1622	0.58	2.33	0.0047
PM_{10}	0.09	1622	0.32	1.29	0.0026
$PM_{2.5}$	0.09	1622	0.32	1.29	0.0026

Notes:
[1] Emission factors supplied by Aggreko.
[2] Maximum daily emissions based on 4 hours of operation per day.
[3] Annual emissions based on 4 hours of operation per quarter.
[4] SO_2 based on S-balance and 0.05% S fuel.

Monantore Mine
Tailings Impoundment
Source Number: 4.1

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Montanore Tailings WE

COMPUTATION OF WIND EROSION EMISSIONS (version 93037)
BASED ON AP-42 SECTION 13.2.5 INDUSTRIAL WIND EROSION

EXAMINE COMPUTED EMISSIONS FOR DISTURBANCE FREQUENCY --
COMPUTATION ASSUMES DISTURBANCE EVERY HOUR




    Particle Size (1=TSP, 2=PM10):  2
    Anemometer Ht (m): 10.00
    Surface Roughness Height Near Anemometer (cm): 15.00
    Surface Roughess Height at Application Site (cm):  0.01
    Threshold Friction Velocity (m/sec):  0.55
    Stockpile or Exposed Surface Area (m2):1618800.
    Surface Type (1=Flat, 2=Stockpile):  1
    Correction Factor: 1.000



  YR  MO DAY  HR   ANEM   THRESHOLD  FRICTION  POTENTIAL POTENTIAL
                   WIND    FRICTION  VELOCITY  EMISSIONS EMISSIONS
                   SPEED   VELOCITY  @SURFACE     (lb)    (g/sec) (g/sec/m2)
                  (m/sec)   (m/sec)   (m/sec)

    NO WIND SPEEDS EXCEEDED THRESHOLD VELOCITY --
    THEREFORE THERE ARE NO WIND EROSION EMISSIONS FOR THIS SURFACE
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Montanore Mine
Concentrate Haul to Rail Siding in Libby
Source Number: 3.1

Vehicle Type	Average Vehicle Weight[1]	Annual Throughput	24-Hour Throughput	Silt Content[2]	24-Hour Round Trips	Annual Round Trips	Round Trip Distance	Annual Vehicle Miles Traveled	24-Hour Vehicle Miles Traveled	PM_{10} Emission Factor[3]	Annual PM_{10} Emissions[4]	24-Hour PM_{10} Emissions[4]	Annual $PM_{2.5}$ Emissions[4]	24-Hour $PM_{2.5}$ Emissions[4]	Annual Lead Emissions
	(tons)	(tpy)	(tons/day)	(g/m^2)	(rt/day)	(rt/yr)	(miles)	(VMT)	(VMT)	(lb/VMT)	(tpy)	(lb/day)	(tpy)	(lb/day)	(tpy)
20-ton Haul Truck	41.70	147,000	420	8.2	21	7,350	40	294,000	840.00	0.52	76.18	435.29	15.24	87.06	7.62E-04

Notes:
[1] Vehicle weight taken from "Caterpillar Performance Handbook, 1994" for Articulated Trucks, Modeled D20D.
[2] AP-42 Supplement E (EPA, 1998), Table 13.2.1-4, Typical Silt Content and Loading Values for Paved Roads at Industrial Facilities
[3] AP-42 (EPA, 2003), Section 13.2.1, "Paved Roads."
[4] Calculated as Emissions in (lb/VMT) x Vehicle Miles Traveled (VMT).

Montanore Mine
Laboratory Crusher
Source Number: 6.1

Annual Throughput (tpy)	Maximum Daily Throughput (tons/day)	PM_{10} Emission Factor[1] (lb/ton)	Annual PM_{10} Emissions (tpy)	Maximum 24-hr PM_{10} Emissions (lb/day)	Annual $PM_{2.5}$ Emissions (tpy)	Maximum 24-hr $PM_{2.5}$ Emissions (lb/day)
365	1	0.16	0.029	0.16	0.01	0.03

Note:
[1] AP-42 (EPA, 1982), Section 11.24, "Metallic Minerals Processing."

Montanore Mine
Mobile Source Diesel Combustion NO_x Emissions
Source Numbers: 1.5 (Underground) and 5.1 (Surface)

Mobile Source	Typical Engine Model	Engine Horsepower (hp)	Number of Units	NO_x Emission Factor (g/hp-hr)	Emission Factor Basis	Equipment Availability and Use of Avail [1]	Load Factor	Maximum 24-Hr Operating Schedule [2] (hr/day)	Maximum 24-Hr Emissions (lb/day)	Annual Operating Schedule [2] (hr/yr)	Annual Average Emissions (tpy)
SURFACE											
Small Vehicles - Pickups [4]	Cummins or Ford or GM	300	10	0.0167	MOBILE6	57.95%	1	6	0.36	2190	0.07
Crew Bus	Cummins	300	2	4.5	Tier 2[3]	57.95%	0.4	6	8.28	2190	1.51
40-ton Haul Truck - Muck	769D Cat - 3408 E	518	3	4.16	Manuf	57.95%	0.4	24	79.29	8760	14.47
Loader	Cat 988 - C18 MEUI	530	3	2.65	Manuf	57.95%	0.4	24	51.68	8760	9.43
Road Grader - 14H	Cat 3176 DITA	220	1	4.1	Manuf	57.95%	0.4	24	11.06	8760	2.02
Bull Dozer	Cat D8 - C15	347	1	2.54	Manuf	57.95%	0.4	24	10.81	8760	1.97
Backhoe	Cat 446 D -3114 DIT	110	1	6.06	Manuf	57.95%	0.4	24	8.18	8760	1.49
Highway Trucks	Mack Truck	300	2	4.5	Tier 2[3]	57.95%	0.4	24	33.12	8760	6.04
UNDERGROUND											
Road Grader - 14H	Cat 3176DITA	220	1	4.1	Manuf	57.95%	0.4	24	11.06	8760	2.02
Personnel Bus	Cat 3056 E	150	1	4.5	Tier 2[3]	57.95%	0.4	6	2.07	2190	0.38
Personnel Transport	Cat 3056 E	150	5	4.5	Tier 2[3]	57.95%	0.4	24	41.40	8760	7.55
Boss Buggy	Deutz BF4M 1013	150	5	4.53	Manuf	57.95%	0.4	24	41.67	8760	7.61
50 Ton Haul Trucks	Detroit DDEC Series 60	575	4	4.5	Tier 2[3]	57.95%	0.4	24	126.95	8760	23.17
50 Ton Haul Trucks	Electric Motor on trolley with DDEC Series 40 for use off trolley line Detroit 706 LTE 81 kw = 110 hp 25% of time operating	110	4	4.5	Tier 2[2]	57.95%	0.4	5	5.06	1825	0.92
26 Ton Haul Trucks	EJC 530 - Detroit Diesel Series 60	400	2	4.5	Tier 2[3]	57.95%	0.4	24	44.16	8760	8.06
Face Shovel Broyt ED 100W	Volvo TWD 1240 VE	375	2	4.5	Tier 2[3]	57.95%	0.4	3	5.17	1095	0.94
3-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	4.53	Manuf	57.95%	0.4	4	3.22	1460	0.59
2-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	4.53	Manuf	57.95%	0.4	4	3.22	1460	0.59
Bench Drill	Electric/Diesel Tram Deutz 1013	116	2	4.53	Manuf	57.95%	0.4	2	1.07	730	0.20
7 CY LHD	Toro 007 - Detroit Series 50	250	2	4.5	Tier 2[3]	57.95%	0.4	24	27.60	8760	5.04
8 CY LHD	Toro 1400 - Detroit S 60	325	2	4.5	Tier 2[3]	57.95%	0.4	24	35.88	8760	6.55
Equipment Tram Generator	300 hp motor on each carrier and gen set	600	1	4.5	Tier 2[3]	57.95%	0.4	8	11.04	2920	2.01
Bolter	Deutz BF4M 1013	150	4	4.53	Manuf	57.95%	0.4	24	33.34	8760	6.08
Scissor Lift	Deutz BF4M 1013	150	3	4.53	Manuf	57.95%	0.4	24	25.00	8760	4.56
Bulk Emulsion Handler Slurry Face Loader	Deutz BF4M 1013	150	2	4.53	Manuf	57.95%	0.4	24	16.67	8760	3.04
Bulk Explosive Truck	Deutz BF4M 1013	150	1	4.53	Manuf	57.95%	0.4	24	8.33	8760	1.52
Water Truck	Deutz BF4M 1013	150	1	4.53	Manuf	57.95%	0.4	24	8.33	8760	1.52
Supply such as Normet	Deutz BF4M 1013	150	3	4.53	Manuf	57.95%	0.4	24	25.00	8760	4.56
Fork Lift	Deutz BF4M 1013	150	2	4.53	Manuf	57.95%	0.4	24	16.67	8760	3.04
Construction Truck	Deutz BF4M 1013	150	1	4.53	Manuf	57.95%	0.4	24	8.33	8760	1.52
Mechanic Truck	Deutz BF4M 1013	150	2	4.53	Manuf	57.95%	0.4	24	16.67	8760	3.04
Electrician Truck	Deutz BF4M 1013	150	2	4.53	Manuf	57.95%	0.4	24	16.67	8760	3.04
Fire Truck	Deutz BF4M 1013	150	1	4.53	Manuf	57.95%	0.4	1	0.35	365	0.06
Fuel/Lube Truck	Deutz BF4M 1013	150	1	4.53	Manuf	57.95%	0.4	24	8.33	8760	1.52
Concrete Transport	Deutz BF4M 1013	150	2	4.53	Manuf	57.95%	0.4	24	16.67	8760	3.04

Underground Equipment Total (tpy)	**102.19**
Underground Maximum 24-Hour Total Emissions (lb/day)	**559.96**
Surface Equipment Total (tpy)	**37.01**
Surface Maximum 24-Hour Total Emissions (lb/day)	**202.81**

Notes

	Use of Avail	Availability	Total Availability
[1] 11 hr/shift, 2 spd, 1.5 hr travel, 0.5 lunch, 50 min/hr = 11-1.5-.5*50/60 = 7.5 eff hr/11 hr s	68.18%	85.00%	57.95%

Availability means, availability of unit due to maintenance or other downtime. Use of availability means percent use of available unit operation time.

[2] 24-hours per day, 365 days/year.

[3] NO_x and HC Emission Factors estimated based on Table 7 of "Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition, NR-009c, EPA, April 2004.

[4] Emission factor based on Table 1 Tier 1 LDDV from "MOBILE6 Estimates of Exhaust Emissions for 1994-and-later Light Duty Diesel Cars and Trucks" EPA, July 2001. Assumptions of 300hp and an average of 5 mi/hr

Montanore Mine
Mobile Source Diesel Combustion PM_{10} and $PM_{2.5}$ Emissions
Source Numbers: 1.5 (Underground) and 5.1 (Surface)

Mobile Source	Typical Engine Model	Engine Horsepower (hp)	Number of Units	PM_{10} Emission Factor (g/hp-hr)	Emission Factor Basis	Equipment Availability and Use of Avail [1]	Load Factor	Maximum 24-Hr Operating Schedule [2] (hr/day)	Maximum 24-Hr Emissions (lb/day)	Annual Operating Schedule [2] (hr/yr)	Annual Average Emissions[3] (tpy)
SURFACE											
Small Vehicles - Pickups	Cummins or Ford or GM	300	10	0.15	Tier 2	57.95%	1	6	3.45	2190	0.63
Crew Bus	Cummins	300	2	0.15	Tier 2	57.95%	0.4	6	0.28	2190	0.05
40-ton Haul Truck - Muck	769D Cat - 3408 E	518	3	0.09	Manuf	57.95%	0.4	24	1.72	8760	0.31
Loader	Cat 988 - C18 MEUI	530	3	0.1	Manuf	57.95%	0.4	24	1.95	8760	0.36
Road Grader - 14H	Cat 3176 DITA	220	1	0.086	Manuf	57.95%	0.4	24	0.23	8760	0.04
Bull Dozer	Cat D8 - C15	347	1	0.136	Manuf	57.95%	0.4	24	0.58	8760	0.11
Backhoe	Cat 446 D -3114 DIT	110	1	0.28	Manuf	57.95%	0.4	24	0.38	8760	0.07
Highway Trucks	Mack Truck	300	2	0.15	Tier 2	57.95%	0.4	24	1.10	8760	0.20
UNDERGROUND											
Road Grader - 14H	Cat 3176DITA	220	1	0.086	Manuf	57.95%	0.4	24	0.23	8760	0.04
Personnel Bus	Cat 3056 E	150	1	0.22	Tier 2	57.95%	0.4	6	0.10	2190	0.02
Personnel Transport	Cat 3056 E	150	5	0.22	Tier 2	57.95%	0.4	24	2.02	8760	0.37
Boss Buggy	Deutz BF4M 1013	150	5	0.04	Manuf	57.95%	0.4	24	0.37	8760	0.07
50 Ton Haul Trucks	Detroit DDEC Series 60	575	4	0.15	Tier 2	57.95%	0.4	24	4.23	8760	0.77
50 Ton Haul Trucks	Electric Motor on trolley with DDEC Series 40 for use off trolley line Detroit 706 LTE 81 kw = 110 hp 25% of time operating	110	4	0.22	Tier 2	57.95%	0.4	5	0.25	1825	0.05
26 Ton Haul Trucks	EJC 530 - Detroit Diesel Series 60	400	2	0.15	Tier 2	57.95%	0.4	24	1.47	8760	0.27
Face Shovel Broyt ED 100W	Volvo TWD 1240 VE	375	2	0.15	Tier 2	57.95%	0.4	3	0.17	1095	0.03
3-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.04	Manuf	57.95%	0.4	4	0.03	1460	0.01
2-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.04	Manuf	57.95%	0.4	4	0.03	1460	0.01
Bench Drill	Electric/Diesel Tram Deutz 1013	116	2	0.04	Manuf	57.95%	0.4	2	0.01	730	0.00
7 CY LHD	Toro 007 - Detroit Series 50	250	2	0.15	Tier 2	57.95%	0.4	24	0.92	8760	0.17
8 CY LHD	Toro 1400 - Detroit S 60	325	2	0.15	Tier 2	57.95%	0.4	24	1.20	8760	0.22
Equipment Tram Generator	300 hp motor on each carrier and gen set	600	1	0.15	Tier 2	57.95%	0.4	8	0.37	2920	0.07
Bolter	Deutz BF4M 1013	150	4	0.04	Manuf	57.95%	0.4	24	0.29	8760	0.05
Scissor Lift	Deutz BF4M 1013	150	3	0.04	Manuf	57.95%	0.4	24	0.22	8760	0.04
Bulk Emulsion Handler Slurry Face Loader	Deutz BF4M 1013	150	2	0.04	Manuf	57.95%	0.4	24	0.15	8760	0.03
Bulk Explosive Truck	Deutz BF4M 1013	150	1	0.04	Manuf	57.95%	0.4	24	0.07	8760	0.01
Water Truck	Deutz BF4M 1013	150	1	0.04	Manuf	57.95%	0.4	24	0.07	8760	0.01
Supply such as Normet	Deutz BF4M 1013	150	3	0.04	Manuf	57.95%	0.4	24	0.22	8760	0.04
Fork Lift	Deutz BF4M 1013	150	2	0.04	Manuf	57.95%	0.4	24	0.15	8760	0.03
Construction Truck	Deutz BF4M 1013	150	1	0.04	Manuf	57.95%	0.4	24	0.07	8760	0.01
Mechanic Truck	Deutz BF4M 1013	150	2	0.04	Manuf	57.95%	0.4	24	0.15	8760	0.03
Electrician Truck	Deutz BF4M 1013	150	2	0.04	Manuf	57.95%	0.4	24	0.15	8760	0.03
Fire Truck	Deutz BF4M 1013	150	1	0.04	Manuf	57.95%	0.4	1	0.00	365	0.00
Fuel/Lube Truck	Deutz BF4M 1013	150	1	0.04	Manuf	57.95%	0.4	24	0.07	8760	0.01
Concrete Transport	Deutz BF4M 1013	150	2	0.04	Manuf	57.95%	0.4	24	0.15	8760	0.03

Underground Equipment Total (tpy)	**2.40**
Underground Maximum 24-Hour Total Emissions (lb/day)	**13.17**
Surface Equipment Total (tpy)	**1.77**
Surface Maximum 24-Hour Total Emissions (lb/day)	**9.68**

Notes:

	Use of Avail	Availability	Total Availability
[1] 11 hr/shift, 2 spd, 1.5 hr travel, 0.5 lunch, 50 min/hr = 11-1.5-.5*50/60 = 7.5 eff hr/11 hr sl	68.18%	85.00%	57.95%

Availability means: availability of unit due to maintenance or other downtime. Use of availability means: percent use of available unit operation time.

[2] 24-hours per day, 365 days/year.

[3] PM2.5 conservatively assumed to be equivalent to PM10 for combustion sources.

Montanore Mine
Mobile Source Diesel Combustion CO Emissions
Source Numbers: 1.5 (Underground) and 5.1 (Surface)

Mobile Source	Typical Engine Model	Engine Horsepower (hp)	Number of Units	CO Emission Factor (g/hp-hr)	Emission Factor Basis	Equipment Availability and Use of Avail [1]	Load Factor	Maximum 24-Hr Operating Schedule [2] (hr/day)	Maximum 24-Hr Emissions (lb/day)	Annual Operating Schedule [2] (hr/yr)	Annual Average Emissions (tpy)
SURFACE											
Small Vehicles - Pickups [3]	Cummins or Ford or GM	300	10	0.0567	MOBILE6	57.95%	1	6	1.30	2190	0.24
Crew Bus	Cummins	300	2	2.6	Tier 2	57.95%	0.4	6	4.78	2190	0.87
40-ton Haul Truck - Muck	769D Cat - 3408 E	518	3	1.02	Manuf	57.95%	0.4	24	19.44	8760	3.55
Loader	Cat 988 - C18 MEUI	530	3	1.47	Manuf	57.95%	0.4	24	28.67	8760	5.23
Road Grader - 14H	Cat 3176 DITA	220	1	0.83	Manuf	57.95%	0.4	24	2.24	8760	0.41
Bull Dozer	Cat D8 - C15	347	1	1.79	Manuf	57.95%	0.4	24	7.62	8760	1.39
Backhoe	Cat 446 D -3114 DIT	110	1	1.81	Manuf	57.95%	0.4	24	2.44	8760	0.45
Highway Trucks	Mack Truck	300	2	2.6	Tier 2	57.95%	0.4	24	19.13	8760	3.49
UNDERGROUND											
Road Grader - 14H	Cat 3176DITA	220	1	0.83	Manuf	57.95%	0.4	24	2.24	8760	0.41
Personnel Bus	Cat 3056 E	150	1	3.7	Tier 2	57.95%	0.4	6	1.70	2190	0.31
Personnel Transport	Cat 3056 E	150	5	3.7	Tier 2	57.95%	0.4	24	34.04	8760	6.21
Boss Buggy	Deutz BF4M 1013	150	5	0.23	Manuf	57.95%	0.4	24	2.12	8760	0.39
50 Ton Haul Trucks	Detroit DDEC Series 60	575	4	2.6	Tier 2	57.95%	0.4	24	73.35	8760	13.39
50 Ton Haul Trucks	Electric Motor on trolley with DDEC Series 40 for use off trolley line Detroit 706 LTE 81 kw = 110 hp 25% of time operating	110	4	3.7	Tier 2	57.95%	0.4	5	4.16	1825	0.76
26 Ton Haul Trucks	EJC 530 - Detroit Diesel Series 60	400	2	2.6	Tier 2	57.95%	0.4	24	25.51	8760	4.66
Face Shovel Broyt ED 100W	Volvo TWD 1240 VE	375	2	2.6	Tier 2	57.95%	0.4	3	2.99	1095	0.55
3-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.23	Manuf	57.95%	0.4	4	0.16	1460	0.03
2-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.23	Manuf	57.95%	0.4	4	0.16	1460	0.03
Bench Drill	Electric/Diesel Tram Deutz 1013	116	2	0.23	Manuf	57.95%	0.4	2	0.05	730	0.01
7 CY LHD	Toro 007 - Detroit Series 50	250	2	2.6	Tier 2	57.95%	0.4	24	15.95	8760	2.91
8 CY LHD	Toro 1400 - Detroit S 60	325	2	2.6	Tier 2	57.95%	0.4	24	20.73	8760	3.78
Equipment Tram Generator	300 hp motor on each carrier and gen set	600	1	2.6	Tier 2	57.95%	0.4	8	6.38	2920	1.16
Bolter	Deutz BF4M 1013	150	4	0.23	Manuf	57.95%	0.4	24	1.69	8760	0.31
Scissor Lift	Deutz BF4M 1013	150	3	0.23	Manuf	57.95%	0.4	24	1.27	8760	0.23
Bulk Emulsion Handler Slurry Face Loader	Deutz BF4M 1013	150	2	0.23	Manuf	57.95%	0.4	24	0.85	8760	0.15
Bulk Explosive Truck	Deutz BF4M 1013	150	1	0.23	Manuf	57.95%	0.4	24	0.42	8760	0.08
Water Truck	Deutz BF4M 1013	150	1	0.23	Manuf	57.95%	0.4	24	0.42	8760	0.08
Supply such as Normet	Deutz BF4M 1013	150	3	0.23	Manuf	57.95%	0.4	24	1.27	8760	0.23
Fork Lift	Deutz BF4M 1013	150	2	0.23	Manuf	57.95%	0.4	24	0.85	8760	0.15
Construction Truck	Deutz BF4M 1013	150	1	0.23	Manuf	57.95%	0.4	24	0.42	8760	0.08
Mechanic Truck	Deutz BF4M 1013	150	2	0.23	Manuf	57.95%	0.4	24	0.85	8760	0.15
Electrician Truck	Deutz BF4M 1013	150	2	0.23	Manuf	57.95%	0.4	24	0.85	8760	0.15
Fire Truck	Deutz BF4M 1013	150	1	0.23	Manuf	57.95%	0.4	1	0.02	365	0.00
Fuel/Lube Truck	Deutz BF4M 1013	150	1	0.23	Manuf	57.95%	0.4	24	0.42	8760	0.08
Concrete Transport	Deutz BF4M 1013	150	2	0.23	Manuf	57.95%	0.4	24	0.85	8760	0.15

Underground Equipment Total (tpy)	**36.45**
Underground Maximum 24-Hour Total Emissions (lb/day)	**199.72**
Surface Equipment Total (tpy)	**9.89**
Surface Maximum 24-Hour Total Emissions (lb/day)	**54.20**

Notes:

	Use of Avail	Availability	Total Availability
[1] 11 hr/shift, 2 spd, 1.5 hr travel, 0.5 lunch, 50 min/hr = 11-1.5-.5*50/60 = 7.5 eff hr/11 hr	68.18%	85.00%	57.95%

Availability means: availability of unit due to maintenance or other downtime. Use of availability means: percent use of available unit operation time.

[2] 24-hours per day, 365 days/year.

[3] Based on Table 1, Tier 1 LDDV from "MOBILE6 Estimates of Exhaust Emissions for 1994-and-later Light Duty Diesel Cars and Trucks" EPA, July 2001. Assumptions of 300hp and an average of 5 mi/hr.

Montanore Mine
Mobile Source Diesel Combustion SO_2 Emissions
Source Numbers: 1.5 (Underground) and 5.1 (Surface)

Mobile Source	Typical Engine Model	Engine Horsepower (hp)	Number of Units	SO_2 Emission Factor (g/hp-hr)	Emission Factor Basis	Equipment Availability and Use of Avail [1]	Load Factor	Maximum 24-Hr Operating Schedule [2] (hr/day)	Maximum 24-Hr Emissions (lb/day)	Annual Operating Schedule [2] (hr/yr)	Annual Average Emissions (tpy)
SURFACE											
Small Vehicles - Pickups	Cummins or Ford or GM	300	10	0.163	S-bal.	57.95%	1	6	3.75	2190	0.68
Crew Bus	Cummins	300	2	0.163	S-bal.	57.95%	0.4	6	0.30	2190	0.05
40-ton Haul Truck - Muck	769D Cat - 3408 E	518	3	0.6641	Manuf	57.95%	0.4	24	12.66	8760	2.31
Loader	Cat 988 - C18 MEUI	530	3	0.6623	Manuf	57.95%	0.4	24	12.92	8760	2.36
Road Grader - 14H	Cat 3176 DITA	220	1	0.7773	Manuf	57.95%	0.4	24	2.10	8760	0.38
Bull Dozer	Cat D8 - C15	347	1	0.6484	Manuf	57.95%	0.4	24	2.76	8760	0.50
Backhoe	Cat 446 D -3114 DIT	110	1	0.7272	Manuf	57.95%	0.4	24	0.98	8760	0.18
Highway Trucks	Mack Truck	300	2	0.163	S-bal.	57.95%	0.4	24	1.20	8760	0.22
UNDERGROUND											
Road Grader - 14H	Cat 3176DITA	220	1	0.7773	Manuf	57.95%	0.4	24	2.10	8760	0.38
Personnel Bus	Cat 3056 E	150	1	0.163	S-bal.	57.95%	0.4	6	0.07	2190	0.01
Personnel Transport	Cat 3056 E	150	5	0.163	S-bal.	57.95%	0.4	24	1.50	8760	0.27
Boss Buggy	Deutz BF4M 1013	150	5	0.17	Manuf	57.95%	0.4	24	1.56	8760	0.29
50 Ton Haul Trucks	Detroit DDEC Series 60	575	4	0.163	S-bal.	57.95%	0.4	24	4.60	8760	0.84
50 Ton Haul Trucks	Electric Motor on trolley with DDEC Series 40 for use off trolley line Detroit 706 LTE 81 kw = 110 hp .25% of time operating	110	4	0.163	S-bal.	57.95%	0.4	5	0.18	1825	0.03
26 Ton Haul Trucks	EJC 530 - Detroit Diesel Series 60	400	2	0.163	S-bal.	57.95%	0.4	24	1.60	8760	0.29
Face Shovel Broyt ED 100W	Volvo TWD 1240 VE	375	2	0.163	S-bal.	57.95%	0.4	3	0.19	1095	0.03
3-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.17	Manuf	57.95%	0.4	4	0.12	1460	0.02
2-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.17	Manuf	57.95%	0.4	4	0.12	1460	0.02
Bench Drill	Electric/Diesel Tram Deutz 1013	116	2	0.17	Manuf	57.95%	0.4	2	0.04	730	0.01
7 CY LHD	Toro 007 - Detroit Series 50	250	2	0.163	S-bal.	57.95%	0.4	24	1.00	8760	0.18
8 CY LHD	Toro 1400 - Detroit S 60	325	2	0.163	S-bal.	57.95%	0.4	24	1.30	8760	0.24
Equipment Tram Generator	300 hp motor on each carrier and gen set	600	1	0.163	S-bal.	57.95%	0.4	8	0.40	2920	0.07
Boiler	Deutz BF4M 1013	150	4	0.17	Manuf	57.95%	0.4	24	1.25	8760	0.23
Scissor Lift	Deutz BF4M 1013	150	3	0.17	Manuf	57.95%	0.4	24	0.94	8760	0.17
Bulk Emulsion Handler Slurry Face Loader	Deutz BF4M 1013	150	2	0.17	Manuf	57.95%	0.4	24	0.63	8760	0.11
Bulk Explosive Truck	Deutz BF4M 1013	150	1	0.17	Manuf	57.95%	0.4	24	0.31	8760	0.06
Water Truck	Deutz BF4M 1013	150	1	0.17	Manuf	57.95%	0.4	24	0.31	8760	0.06
Supply such as Normet	Deutz BF4M 1013	150	3	0.17	Manuf	57.95%	0.4	24	0.94	8760	0.17
Fork Lift	Deutz BF4M 1013	150	2	0.17	Manuf	57.95%	0.4	24	0.63	8760	0.11
Construction Truck	Deutz BF4M 1013	150	1	0.17	Manuf	57.95%	0.4	24	0.31	8760	0.06
Mechanic Truck	Deutz BF4M 1013	150	2	0.17	Manuf	57.95%	0.4	24	0.63	8760	0.11
Electrician Truck	Deutz BF4M 1013	150	2	0.17	Manuf	57.95%	0.4	24	0.63	8760	0.11
Fire Truck	Deutz BF4M 1013	150	1	0.17	Manuf	57.95%	0.4	1	0.01	365	0.00
Fuel/Lube Truck	Deutz BF4M 1013	150	1	0.17	Manuf	57.95%	0.4	24	0.31	8760	0.06
Concrete Transport	Deutz BF4M 1013	150	2	0.17	Manuf	57.95%	0.4	24	0.63	8760	0.11

Underground Equipment Total (tpy)	**4.07**
Underground Maximum 24-Hour Total Emissions (lb/day)	**22.31**
Surface Equipment Total (tpy)	**5.41**
Surface Maximum 24-Hour Total Emissions (lb/day)	**29.62**

Notes:

	Use of Avail	Availability	Total Availability
[1] 11 hr/shift, 2 spd, 1.5 hr travel, 0.5 lunch, 50 min/hr = 11-1.5-.5*50/60 = 7.5 eff hr/11 hr :	68.18%	85.00%	57.95%

Availability means: availability of unit due to maintenance or other downtime. Use of availability means: percent use of available unit operation time.

[2] 24-hours per day, 365 days/year.

Montanore Mine
Mobile Source Diesel Combustion VOC Emissions
Source Numbers: 1.5 (Underground) and 5.1 (Surface)

Mobile Source	Typical Engine Model	Engine Horsepower (hp)	Number of Units	AP-42 VOC Emission Factor (g/hp-hr)	Emission Factor Basis	Equipment Availability and Use of Avail [1]	Load Factor	Escape Factor	Maximum 24-Hr Operating Schedule [2] (hr/day)	Maximum 24-Hr Emissions (lb/day)	Annual Operating Schedule [2] (hr/yr)	Annual Average Emissions (tpy)
SURFACE												
Small Vehicles - Pickups [4]	Cummins or Ford or GM	300	10	0.004	MOBILE6	57.95%	1	N/A	6	0.09	2190	0.02
Crew Bus	Cummins	300	2	0.4	Tier 2[3]	57.95%	0.4	N/A	6	0.74	2190	0.13
40-ton Haul Truck - Muck	769D Cat - 3408 E	518	3	0.1	Manuf	57.95%	0.4	N/A	24	1.91	8760	0.35
Loader	Cat 988 - C18 MEUI	530	3	0.1	Manuf	57.95%	0.4	N/A	24	1.95	8760	0.36
Road Grader - 14H	Cat 3176 DITA	220	1	0.19	Manuf	57.95%	0.4	N/A	24	0.51	8760	0.09
Bull Dozer	Cat D8 - C15	347	1	0.21	Manuf	57.95%	0.4	N/A	24	0.89	8760	0.16
Backhoe	Cat 446 D -3114 DIT	110	1	0.31	Manuf	57.95%	0.4	N/A	24	0.42	8760	0.08
Highway Trucks	Mack Truck	300	2	0.4	Tier 2[3]	57.95%	0.4	N/A	24	2.94	8760	0.54
UNDERGROUND												
Road Grader - 14H	Cat 3176DITA	220	1	0.19	Manuf	57.95%	0.4	1.00	24	0.51	8760	0.09
Personnel Bus	Cat 3056 E	150	1	0.4	Tier 2[3]	57.95%	0.4	1.00	6	0.18	2190	0.03
Personnel Transport	Cat 3056 E	150	5	0.4	Tier 2[3]	57.95%	0.4	1.00	24	3.68	8760	0.67
Boss Buggy	Deutz BF4M 1013	150	5	0.07	Manuf	57.95%	0.4	1.00	24	0.64	8760	0.12
50 Ton Haul Trucks	Detroit DDEC Series 60	575	4	0.4	Tier 2[3]	57.95%	0.4	1.00	24	11.28	8760	2.06
50 Ton Haul Trucks	Electric Motor on trolley with DDEC Series 40 for use off trolley line Detroit 706 LTE 81 kw = 110 hp 25% of time operating	110	4	0.4	Tier 2[3]	57.95%	0.4	1.00	5	0.45	1825	0.08
26 Ton Haul Trucks	EJC 530 - Detroit Diesel Series 60	400	2	0.3	Tier 2[3]	57.95%	0.4	1.00	24	2.94	8760	0.54
Face Shovel Broyt ED 100W	Volvo TWD 1240 VE	375	2	0.3	Tier 2[3]	57.95%	0.4	1.00	3	0.34	1095	0.06
3-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.07	Manuf	57.95%	0.4	1.00	4	0.05	1460	0.01
2-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.07	Manuf	57.95%	0.4	1.00	4	0.05	1460	0.01
Bench Drill	Electric/Diesel Tram Deutz 1013	116	2	0.07	Manuf	57.95%	0.4	1.00	2	0.02	730	0.00
7 CY LHD	Toro 007 - Detroit Series 50	250	2	0.4	Tier 2[3]	57.95%	0.4	1.00	24	2.45	8760	0.45
8 CY LHD	Toro 1400 - Detroit S 60	325	2	0.3	Tier 2[3]	57.95%	0.4	1.00	24	2.39	8760	0.44
Equipment Tram Generator	300 hp motor on each carrier and gen set	600	1	0.3	Tier 2[3]	57.95%	0.4	1.00	8	0.74	2920	0.13
Bolter	Deutz BF4M 1013	150	4	0.07	Manuf	57.95%	0.4	1.00	24	0.52	8760	0.09
Scissor Lift	Deutz BF4M 1013	150	3	0.07	Manuf	57.95%	0.4	1.00	24	0.39	8760	0.07
Bulk Emulsion Handler Slurry Face Loader	Deutz BF4M 1013	150	2	0.07	Manuf	57.95%	0.4	1.00	24	0.26	8760	0.05
Bulk Explosive Truck	Deutz BF4M 1013	150	1	0.07	Manuf	57.95%	0.4	1.00	24	0.13	8760	0.02
Water Truck	Deutz BF4M 1013	150	1	0.07	Manuf	57.95%	0.4	1.00	24	0.13	8760	0.02
Supply such as Normet	Deutz BF4M 1013	150	3	0.07	Manuf	57.95%	0.4	1.00	24	0.39	8760	0.07
Fork Lift	Deutz BF4M 1013	150	2	0.07	Manuf	57.95%	0.4	1.00	24	0.26	8760	0.05
Construction Truck	Deutz BF4M 1013	150	1	0.07	Manuf	57.95%	0.4	1.00	24	0.13	8760	0.02
Mechanic Truck	Deutz BF4M 1013	150	2	0.07	Manuf	57.95%	0.4	1.00	24	0.26	8760	0.05
Electrician Truck	Deutz BF4M 1013	150	2	0.07	Manuf	57.95%	0.4	1.00	24	0.26	8760	0.05
Fire Truck	Deutz BF4M 1013	150	1	0.07	Manuf	57.95%	0.4	1.00	1	0.01	365	0.00
Fuel/Lube Truck	Deutz BF4M 1013	150	1	0.07	Manuf	57.95%	0.4	1.00	24	0.13	8760	0.02
Concrete Transport	Deutz BF4M 1013	150	2	0.07	Manuf	57.95%	0.4	1.00	24	0.26	8760	0.05

Underground Equipment Total (tpy)	**5.26**
Underground Maximum 24-Hour Total Emissions (lb/day)	**28.84**
Surface Equipment Total (tpy)	**1.73**
Surface Maximum 24-Hour Total Emissions (lb/day)	**9.45**

Notes:

	Use of Avail	Availability	Total Availability
[1] 11 hr/shift, 2 spd, 1.5 hr travel, 0.5 lunch, 50 min/hr = 11-1.5-.5*50/60 = 7.5 eff hr/11 hr s	68.18%	85.00%	57.95%

Availability means: availability of unit due to maintenance or other downtime. Use of availability means: percent use of available unit operation time.

[2] 24-hours per day, 365 days/year.

[3] NO_x and HC Emission Factors estimated based on Table 7 of "Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling–Compression-Ignition, NR-009c, EPA, April 2004.

[4] Based on Table 1, Tier 1 LDDV from "MOBILE6 Estimates of Exhaust Emissions for 1994-and-later Light Duty Diesel Cars and Trucks" EPA, July 2001. Assumptions of 300hp and an average of 5 mi/hr.

Montanore Mine
Modeled Emission Rates

	Portal Release (%)	NO_x (g/s) 1-Hour	NO_x (g/s) Annual	PM_{10} (g/s) 24-Hour	PM_{10} (g/s) Annual	$PM_{2.5}$ (g/s) 24 Hour	$PM_{2.5}$ (g/s) Annual	1,3 Hour	SO_2 (g/s) 24-hour	SO_2 (g/s) Annual	Lead g/s	As g/s	Sb g/s	Cr g/s	Cd g/s
Ramsey Portal - 500,000 cfm															
Blasting - Particulate	71%	–	–	0.0008	0.0008	0.0005	0.0005	–	–	–	4.13E-08	1.65E-07	1.65E-08	2.48E-08	1.65E-08
Blasting - Gaseous	71%	0.0164	0.0177	–	–	–	–	0.0006	0.0006	0.0006	–	–	–	–	–
Propane Heaters	71%	0.0786	0.0325	0.0035	0.0014	0.0035	0.0014	2.7636E-05	0.0000	1.1433E-05	–	–	–	–	–
Primary Crushers	71%	–	–	0.0162	0.0155	0.0140	0.0134	–	–	–	8.10E-07	3.24E-06	3.24E-07	4.86E-07	3.24E-07
Coarse Ore Conveyor Transfers	71%	–	–	0.0348	0.0334	0.0300	0.0288	–	–	–	1.74E-06	6.96E-06	6.96E-07	1.04E-06	6.96E-07
Underground Mobile	71%	1.3643	1.3643	0.0494	0.0494	0.0494	0.0494	0.0167	0.0167	0.0167	–	–	–	–	–
Total Ramsey Portal:		**1.4614**	**1.4146**	**0.1046**	**0.1005**	**0.0973**	**0.0934**	**0.0174**	**0.0174**	**0.0173**	**2.59E-06**	**1.04E-05**	**1.04E-06**	**1.55E-06**	**1.04E-06**
Libby Portal - 200,000 cfm															
Blasting - Particulate	29%	–	–	0.0003	0.0003	0.0002	0.0002	–	–		1.65E-08	6.61E-08	6.61E-09	9.92E-09	6.61E-09
Blasting - Gaseous	29%	0.0074	0.0071	–	–	–	–	0.0002	0.0002	0.0002	–	–	–	–	–
Propane Heaters	29%	0.0315	0.0130	0.0014	0.0006	0.0014	0.0006	1.1070E-05	0.0000	0.0000	–	–	–	–	–
Primary Crushers	29%	–	–	0.0065	0.0062	0.0056	0.0054	–	–	–	3.24E-07	1.30E-06	1.30E-07	1.95E-07	1.30E-07
Coarse Ore Conveyor Transfers	29%	–	–	0.0139	0.0134	0.0120	0.0115	–	–	–	6.97E-07	2.79E-06	2.79E-07	4.18E-07	2.79E-07
Underground Mobile	29%	0.5465	0.5465	0.0198	0.0198	0.0198	0.0198	0.0067	0.0067	0.0067	–	–	–	–	–
Total Libby Portal:		**0.5854**	**0.5666**	**0.0419**	**0.0402**	**0.0390**	**0.0374**	**0.0070**	**0.0070**	**0.0069**	**1.04E-06**	**4.15E-06**	**4.15E-07**	**6.23E-07**	**4.15E-07**
Mill Process Sources															
Conveyor to Coarse Ore Stockpile		–	–	0.0420	0.0403	0.0084	0.0081	–	–	–	2.10E-06	8.40E-06	8.40E-07	1.26E-06	8.40E-07
Apron Feeders		–	–	0.0210	0.0201	0.0042	0.0040	–	–	–	1.05E-06	4.20E-06	4.20E-07	6.30E-07	4.20E-07
Conveyor Discharge to SAG Mill		–	–	0.0210	0.0201	0.0042	0.0040	–	–	–	1.05E-06	4.20E-06	4.20E-07	6.30E-07	4.20E-07
Concentrate Transfer		–	–	0.0001	0.0001	0.0000	0.0000	–	–	–	4.41E-09	1.76E-08	1.76E-09	2.65E-09	1.76E-09
Concentrate Loading		–	–	0.0001	0.0001	0.0000	0.0000	–	–	–	4.41E-09	1.76E-08	1.76E-09	2.65E-09	1.76E-09
Oversize Transfer to Hopper		–	–	0.0021	0.0020	0.0004	0.0004	–	–	–	1.05E-07	4.20E-07	4.20E-08	6.30E-08	4.20E-08
Oversize Reclaim Belt Transfer		–	–	0.0021	0.0020	0.0004	0.0004	–	–	–	1.05E-07	4.20E-07	4.20E-08	6.30E-08	4.20E-08
Oversize Crusher		–	–	0.0105	0.0101	0.0021	0.0020	–	–	–	5.25E-07	2.10E-06	2.10E-07	3.15E-07	2.10E-07
Oversize Screen		–	–	0.0021	0.0020	0.0004	0.0004	–	–	–	1.05E-07	4.20E-07	4.20E-08	6.30E-08	4.20E-08
Belt Transfer Back to SAG Mill		–	–	0.0021	0.0020	0.0004	0.0004	–	–	–	1.05E-07	4.20E-07	4.20E-08	6.30E-08	4.20E-08
Total Mill Process Sources:		–	–	**0.1031**	**0.0988**	**0.0206**	**0.0198**	–	–	–	**5.15E-06**	**2.06E-05**	**2.06E-06**	**3.09E-06**	**2.06E-06**
Mill Mobile Sources															
Small Vehicles - Pickups (100%)		0.0020	0.0020	0.0181	0.0181	0.0181	0.0181	0.0197	0.0197	0.0197	–				
Crew Bus (100%)		0.0435	0.0435	0.0014	0.0014	0.0014	0.0014	0.0016	0.0016	0.0016	–				
40-ton Haul Truck - Muck (33.3%)		0.1387	0.1387	0.0030	0.0030	0.0030	0.0030	0.0221	0.0221	0.0221	–				
Loader (66.7%) (2) at mill		0.1809	0.1809	0.0068	0.0068	0.0068	0.0068	0.0452	0.0452	0.0452	–				
Road Grader (10%)		0.0058	0.0058	0.0001	0.0001	0.0001	0.0001	0.0011	0.0011	0.0011	–				
Bull Dozer (25%)		0.0142	0.0142	0.0008	0.0008	0.0008	0.0008	0.0036	0.0036	0.0036	–				
Backhoe (33.3%)		0.0143	0.0143	0.0007	0.0007	0.0007	0.0007	0.0017	0.0017	0.0017	–				
Highway Trucks (10%)		0.0174	0.0174	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	–				
Total Mill Mobile Sources:		**0.4168**	**0.4168**	**0.0315**	**0.0315**	**0.0315**	**0.0315**	**0.0957**	**0.0957**	**0.0957**	–				
Emergency Generator															
Emergency Generator		**2.5536**	**0.0063**	**0.0068**	**0.0001**	**0.0068**	**0.0001**	**0.0734**	**0.0122**	**0.0001**	–				
Tailings Mobile Sources															
40-ton Haul Truck - Muck (33.3%)		0.1387	0.1387	0.0030	0.0030	0.0030	0.0030	0.0221	0.0221	0.0221	–				
Road Grader (90%)		0.0523	0.0523	0.0011	0.0011	0.0011	0.0011	0.0099	0.0099	0.0099	–				
Bull Dozer (60%)		0.0341	0.0341	0.0018	0.0018	0.0018	0.0018	0.0087	0.0087	0.0087	–				
Backhoe (33.3%)		0.0143	0.0143	0.0007	0.0007	0.0007	0.0007	0.0017	0.0017	0.0017	–				
Total Tailings Mobile Sources:		**0.2394**	**0.2394**	**0.0066**	**0.0066**	**0.0066**	**0.0066**	**0.0425**	**0.0425**	**0.0425**	–				
LAD Mobile Sources															
40-ton Haul Truck - Muck (33.3%)		0.1387	0.1387	0.0030	0.0030	0.0030	0.0030	0.0221	0.0221	0.0221	–				
Bull Dozer (15%)		0.0085	0.0085	0.0005	0.0005	0.0005	0.0005	0.0022	0.0022	0.0022	–				
Backhoe (33.3%)		0.0143	0.0143	0.0007	0.0007	0.0007	0.0007	0.0017	0.0017	0.0017	–				
Total LAD Mobile Sources:		**0.1616**	**0.1616**	**0.0041**	**0.0041**	**0.0041**	**0.0041**	**0.0260**	**0.0260**	**0.0260**	–				
Loader at Libby Portal															
Loader (33%)		**0.0904**	**0.0904**	**0.0034**	**0.0034**	**0.0034**	**0.0034**	**0.0226**	**0.0226**	**0.0226**	–				
Lab Crusher		–	–	**0.0008**	**0.0008**	**0.0002**	**0.0002**	–	–	–	–				
Fire Assay Furnace		?		?		?		?							

	Source	Area (m2)	S.T g/sec/m2	Annual g/sec/m2	S.T g/sec/m2	Annual g/sec/m2	S.T g/sec/m2	Annual g/sec/m2	S.T g/sec/m2	S.T g/sec/m3	Annual g/sec/m2	g/sec/m2				
Modeled Area Source Emission Rates	Mill Surface Equip	90000	4.631E-06	4.631E-06	1.505E-06	1.458E-06	5.810E-07	5.716E-07	1.063E-06	1.063E-06	1.063E-06	5.73E-11	2.29E-10	2.29E-11	3.44E-11	2.29E-11
	Tailings (Mobile Srcs)	1188573.6	2.014E-07	2.014E-07	5.538E-09	5.538E-09	5.538E-09	5.538E-09	3.573E-08	3.573E-08	3.573E-08	–				
	LAD	62500	2.585E-06	2.585E-06	6.590E-08	6.590E-08	6.590E-08	6.590E-08	4.166E-07	4.166E-07	4.166E-07	–				
	Libby Loader	225	4.020E-04	4.020E-04	1.517E-05	1.517E-05	1.517E-05	1.517E-05	1.005E-04	1.005E-04	1.005E-04	–				

APPENDIX D

CONSTRUCTION EMISSIONS INVENTORY

Montanore Mine
Phase I Construction Emissions Inventory
Emissions Summary

	NO_x		PM_{10}		$PM_{2.5}$		CO		SO_2		VOC	
	(lb/day)	(tpy)	(lb/day)	(tpy)	(lb/day)	(tpy)	(lb/day)	(tpy)	(lb/day)	(tpy)	(lb/day)	(tpy)
Libby Portal Emissions	160.15	29.23	3.77	0.69	3.77	0.69	57.12	10.42	6.38	1.16	8.25	1.51
Phase I Construction Generator (Libby Site)	549.26	100.24	7.72	1.41	7.72	1.41	26.60	4.86	13.99	2.55	16.31	2.98
Total Construction Phase Maximum:	**709.41**	**129.47**	**11.49**	**2.10**	**11.49**	**2.10**	**83.72**	**15.28**	**20.37**	**3.72**	**24.55**	**4.48**

Construction Test Run Modeled Emission Rates						
Libby Portal (g/s) max (W/ Deposition in Mine)	0.5465	0.0198	0.0198	0.2999	0.0335	0.0433
Generator (g/s) max	2.8836	0.0406	0.0406	0.1397	0.0734	0.0856

Montanore Mine

Phase I Construction Mobile Source Diesel Combustion NO_x Emissions

Note: 28.6% of total underground production estimates used as estimate. as is the underground percentage through the Libby portal during production.

Mobile Source	Typical Engine Model	Engine Horsepower (hp)	Number of Units	NO_x Emission Factor (g/hp-hr)	Emission Factor Basis	Equipment Availability and Use of Avail [1]	Load Factor	Maximum 24-Hr Operating Schedule [2] (hr/day)	Maximum 24-Hr Emissions (lb/day)	Annual Operating Schedule [2] (hr/yr)	Annual Average Emissions (tpy)
UNDERGROUND											
Road Grader - 14H	Cat 3176DITA	220	1	4.1	Manuf	57.95%	0.4	24	3.16	8760	0.58
Personnel Bus	Cat 3056 E	150	1	4.5	Tier 2[3]	57.95%	0.4	6	0.59	2190	0.11
Personnel Transport	Cat 3056 E	150	5	4.5	Tier 2[3]	57.95%	0.4	24	11.84	8760	2.16
Boss Buggy	Deutz BF4M 1013	150	5	4.53	Manuf	57.95%	0.4	24	11.92	8760	2.18
50 Ton Haul Trucks	Detroit DDEC Series 60	575	4	4.5	Tier 2[3]	57.95%	0.4	24	36.31	8760	6.63
50 Ton Haul Trucks	Electric Motor on trolley with DDEC Series 40 for use off trolley line Detroit 706 LTE 81 kw = 110 hp 25% of time operating	110	4	4.5	Tier 2[3]	57.95%	0.4	5	1.45	1825	0.26
26 Ton Haul Trucks	EJC 530 - Detroit Diesel Series 60	400	2	4.5	Tier 2[3]	57.95%	0.4	24	12.63	8760	2.30
Face Shovel Broyt ED 100W	Volvo TWD 1240 VE	375	2	4.5	Tier 2[3]	57.95%	0.4	3	1.48	1095	0.27
3-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	4.53	Manuf	57.95%	0.4	4	0.92	1460	0.17
2-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	4.53	Manuf	57.95%	0.4	4	0.92	1460	0.17
Bench Drill	Electric/Diesel Tram Deutz 1013	116	2	4.53	Manuf	57.95%	0.4	2	0.31	730	0.06
7 CY LHD	Toro 007 - Detroit Series 50	250	2	4.5	Tier 2[3]	57.95%	0.4	24	7.89	8760	1.44
8 CY LHD	Toro 1400 - Detroit S 60	325	2	4.5	Tier 2[3]	57.95%	0.4	24	10.26	8760	1.87
Equipment Tram Generator	300 hp motor on each carrier and gen set	600	1	4.5	Tier 2[3]	57.95%	0.4	8	3.16	2920	0.58
Bolter	Deutz BF4M 1013	150	4	4.53	Manuf	57.95%	0.4	24	9.53	8760	1.74
Scissor Lift	Deutz BF4M 1013	150	3	4.53	Manuf	57.95%	0.4	24	7.15	8760	1.31
Bulk Emulsion Handler Slurry Face Loader	Deutz BF4M 1013	150	2	4.53	Manuf	57.95%	0.4	24	4.77	8760	0.87
Bulk Explosive Truck	Deutz BF4M 1013	150	1	4.53	Manuf	57.95%	0.4	24	2.38	8760	0.44
Water Truck	Deutz BF4M 1013	150	1	4.53	Manuf	57.95%	0.4	24	2.38	8760	0.44
Supply such as Normet	Deutz BF4M 1013	150	3	4.53	Manuf	57.95%	0.4	24	7.15	8760	1.31
Fork Lift	Deutz BF4M 1013	150	2	4.53	Manuf	57.95%	0.4	24	4.77	8760	0.87
Construction Truck	Deutz BF4M 1013	150	1	4.53	Manuf	57.95%	0.4	24	2.38	8760	0.44
Mechanic Truck	Deutz BF4M 1013	150	2	4.53	Manuf	57.95%	0.4	24	4.77	8760	0.87
Electrician Truck	Deutz BF4M 1013	150	2	4.53	Manuf	57.95%	0.4	24	4.77	8760	0.87
Fire Truck	Deutz BF4M 1013	150	1	4.53	Manuf	57.95%	0.4	1	0.10	365	0.02
Fuel/Lube Truck	Deutz BF4M 1013	150	1	4.53	Manuf	57.95%	0.4	24	2.38	8760	0.44
Concrete Transport	Deutz BF4M 1013	150	2	4.53	Manuf	57.95%	0.4	24	4.77	8760	0.87

Underground Libby Phase I Equipment Total (tpy) 29.23

Underground Maximum Libby Portal Phase I 24-Hour Total Emissions (lb/day) 160.15

Notes:	Use of Avail	Availability	Total Availability
[1] 11 hr/shift, 2 spd, 1.5 hr travel, 0.5 lunch, 50 min/hr = 11-1.5-.5*50/60 = 7.5 eff hr/11 hr s	68.18%	85.00%	57.95%

Availability means: availability of unit due to maintenance or other downtime. Use of availability means: percent use of available unit operation time

[2] 24-hours per day, 365 days/year.

[3] NO_x and HC Emission Factors estimated based on Table 7 of "Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition, NR-009c, EPA, April 2004.

[4] Emission factor based on Table 1, Tier 1 LDDV from "MOBILE6 Estimates of Exhaust Emissions for 1994-and-later Light Duty Diesel Cars and Trucks" EPA, July 2001. Assumptions of 300hp and an average of 5 mi/hr.

Montanore Mine

Phase I Construction Mobile Source Diesel Combustion PM_{10} and $PM_{2.5}$ Emissions

Note: 28.6% of total underground production estimates used as estimate, as is the underground percentage through the Libby portal during production.

Mobile Source	Typical Engine Model	Engine Horsepower (hp)	Number of Units	PM_{10} Emission Factor (g/hp-hr)	Emission Factor Basis	Equipment Availability and Use of Avail [1]	Load Factor	Maximum 24-Hr Operating Schedule [2] (hr/day)	Maximum 24-Hr Emissions (lb/day)	Annual Operating Schedule [2] (hr/yr)	Annual Average Emissions[3] (tpy)
UNDERGROUND											
Road Grader - 14H	Cat 3176DITA	220	1	0.086	Manuf	57.95%	0.4	24	0.07	8760	0.01
Personnel Bus	Cat 3056 E	150	1	0.22	Tier 2	57.95%	0.4	6	0.03	2190	0.01
Personnel Transport	Cat 3056 E	150	5	0.22	Tier 2	57.95%	0.4	24	0.58	8760	0.11
Boss Buggy	Deutz BF4M 1013	150	5	0.04	Manuf	57.95%	0.4	24	0.11	8760	0.02
50 Ton Haul Trucks	Detroit DDEC Series 60	575	4	0.15	Tier 2	57.95%	0.4	24	1.21	8760	0.22
50 Ton Haul Trucks	Electric Motor on trolley with DDEC Series 40 for use off trolley line Detroit 706 LTE 81 kw = 110 hp 25% of time operating	110	4	0.22	Tier 2	57.95%	0.4	5	0.07	1825	0.01
26 Ton Haul Trucks	EJC 530 - Detroit Diesel Series 60	400	2	0.15	Tier 2	57.95%	0.4	24	0.42	8760	0.08
Face Shovel Broyt ED 100W	Volvo TWD 1240 VE	375	2	0.15	Tier 2	57.95%	0.4	3	0.05	1095	0.01
3-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.04	Manuf	57.95%	0.4	4	0.01	1460	0.00
2-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.04	Manuf	57.95%	0.4	4	0.01	1460	0.00
Bench Drill	Electric/Diesel Tram Deutz 1013	116	2	0.04	Manuf	57.95%	0.4	2	0.00	730	0.00
7 CY LHD	Toro 007 - Detroit Series 50	250	2	0.15	Tier 2	57.95%	0.4	24	0.26	8760	0.05
8 CY LHD	Toro 1400 - Detroit S 60	325	2	0.15	Tier 2	57.95%	0.4	24	0.34	8760	0.06
Equipment Tram Generator	300 hp motor on each carrier and gen set	600	1	0.15	Tier 2	57.95%	0.4	8	0.11	2920	0.02
Bolter	Deutz BF4M 1013	150	4	0.04	Manuf	57.95%	0.4	24	0.08	8760	0.02
Scissor Lift	Deutz BF4M 1013	150	3	0.04	Manuf	57.95%	0.4	24	0.06	8760	0.01
Bulk Emulsion Handler Slurry Face Loader	Deutz BF4M 1013	150	2	0.04	Manuf	57.95%	0.4	24	0.04	8760	0.01
Bulk Explosive Truck	Deutz BF4M 1013	150	1	0.04	Manuf	57.95%	0.4	24	0.02	8760	0.00
Water Truck	Deutz BF4M 1013	150	1	0.04	Manuf	57.95%	0.4	24	0.02	8760	0.00
Supply such as Normet	Deutz BF4M 1013	150	3	0.04	Manuf	57.95%	0.4	24	0.06	8760	0.01
Fork Lift	Deutz BF4M 1013	150	2	0.04	Manuf	57.95%	0.4	24	0.04	8760	0.01
Construction Truck	Deutz BF4M 1013	150	1	0.04	Manuf	57.95%	0.4	24	0.02	8760	0.00
Mechanic Truck	Deutz BF4M 1013	150	2	0.04	Manuf	57.95%	0.4	24	0.04	8760	0.01
Electrician Truck	Deutz BF4M 1013	150	2	0.04	Manuf	57.95%	0.4	24	0.04	8760	0.01
Fire Truck	Deutz BF4M 1013	150	1	0.04	Manuf	57.95%	0.4	1	0.00	365	0.00
Fuel/Lube Truck	Deutz BF4M 1013	150	1	0.04	Manuf	57.95%	0.4	24	0.02	8760	0.00
Concrete Transport	Deutz BF4M 1013	150	2	0.04	Manuf	57.95%	0.4	24	0.04	8760	0.01

Underground Equipment Total (tpy)	**0.69**
Underground Maximum 24-Hour Total Emissions (lb/day)	**3.77**

Notes:

	Use of Avail	Availability	Total Availability
[1] 11 hr/shift, 2 spd, 1.5 hr travel, 0.5 lunch, 50 min/hr = 11-1.5-.5*50/60 = 7.5 eff hr/11 hr sh	68.18%	85.00%	57.95%

Availability means: availability of unit due to maintenance or other downtime. Use of availability means: percent use of available unit operation time.

[2] 24-hours per day, 365 days/year.

[3] PM2.5 conservatively assumed to be equivalent to PM10 for combustion sources.

Montanore Mine
Phase I Construction Mobile Source Diesel Combustion CO Emissions
Note: 28.6% of total underground production estimates used as estimate, as is the underground percentage through the Libby portal during production.

Mobile Source	Typical Engine Model	Engine Horsepower	Number of Units	CO Emission Factor	Emission Factor Basis	Equipment Availability and Use of Avail [1]	Load Factor	Maximum 24-Hr Operating Schedule [2]	Maximum 24-Hr Emissions	Annual Operating Schedule [2]	Annual Average Emissions
		(hp)		(g/hp-hr)				(hr/day)	(lb/day)	(hr/yr)	(tpy)
UNDERGROUND											
Road Grader - 14H	Cat 3176DITA	220	1	0.83	Manuf	57.95%	0.4	24	0.64	8760	0.12
Personnel Bus	Cat 3056 E	150	1	3.7	Tier 2	57.95%	0.4	6	0.49	2190	0.09
Personnel Transport	Cat 3056 E	150	5	3.7	Tier 2	57.95%	0.4	24	9.73	8760	1.78
Boss Buggy	Deutz BF4M 1013	150	5	0.23	Manuf	57.95%	0.4	24	0.61	8760	0.11
50 Ton Haul Trucks	Detroit DDEC Series 60	575	4	2.6	Tier 2	57.95%	0.4	24	20.98	8760	3.83
50 Ton Haul Trucks	Electric Motor on trolley with DDEC Series 40 for use off trolley line Detroit 706 LTE 81 kw = 110 hp 25% of time operating	110	4	3.7	Tier 2	57.95%	0.4	5	1.19	1825	0.22
26 Ton Haul Trucks	EJC 530 - Detroit Diesel Series 60	400	2	2.6	Tier 2	57.95%	0.4	24	7.30	8760	1.33
Face Shovel Broyt ED 100W	Volvo TWD 1240 VE	375	2	2.6	Tier 2	57.95%	0.4	3	0.86	1095	0.16
3-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.23	Manuf	57.95%	0.4	4	0.05	1460	0.01
2-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.23	Manuf	57.95%	0.4	4	0.05	1460	0.01
Bench Drill	Electric/Diesel Tram Deutz 1013	116	2	0.23	Manuf	57.95%	0.4	2	0.02	730	0.00
7 CY LHD	Toro 007 - Detroit Series 50	250	2	2.6	Tier 2	57.95%	0.4	24	4.56	8760	0.83
8 CY LHD	Toro 1400 - Detroit S 60	325	2	2.6	Tier 2	57.95%	0.4	24	5.93	8760	1.08
Equipment Tram Generator	300 hp motor on each carrier and gen set	600	1	2.6	Tier 2	57.95%	0.4	8	1.82	2920	0.33
Bolter	Deutz BF4M 1013	150	4	0.23	Manuf	57.95%	0.4	24	0.48	8760	0.09
Scissor Lift	Deutz BF4M 1013	150	3	0.23	Manuf	57.95%	0.4	24	0.36	8760	0.07
Bulk Emulsion Handler Slurry Face Loader	Deutz BF4M 1013	150	2	0.23	Manuf	57.95%	0.4	24	0.24	8760	0.04
Bulk Explosive Truck	Deutz BF4M 1013	150	1	0.23	Manuf	57.95%	0.4	24	0.12	8760	0.02
Water Truck	Deutz BF4M 1013	150	1	0.23	Manuf	57.95%	0.4	24	0.12	8760	0.02
Supply such as Normet	Deutz BF4M 1013	150	3	0.23	Manuf	57.95%	0.4	24	0.36	8760	0.07
Fork Lift	Deutz BF4M 1013	150	2	0.23	Manuf	57.95%	0.4	24	0.24	8760	0.04
Construction Truck	Deutz BF4M 1013	150	1	0.23	Manuf	57.95%	0.4	24	0.12	8760	0.02
Mechanic Truck	Deutz BF4M 1013	150	2	0.23	Manuf	57.95%	0.4	24	0.24	8760	0.04
Electrician Truck	Deutz BF4M 1013	150	2	0.23	Manuf	57.95%	0.4	24	0.24	8760	0.04
Fire Truck	Deutz BF4M 1013	150	1	0.23	Manuf	57.95%	0.4	1	0.01	365	0.00
Fuel/Lube Truck	Deutz BF4M 1013	150	1	0.23	Manuf	57.95%	0.4	24	0.12	8760	0.02
Concrete Transport	Deutz BF4M 1013	150	2	0.23	Manuf	57.95%	0.4	24	0.24	8760	0.04

Underground Equipment Total (tpy) 10.42
Underground Maximum 24-Hour Total Emissions (lb/day) 57.12

Notes:

	Use of Avail	Availability	Total Availability
[1] 11 hr/shift, 2 spd, 1.5 hr travel, 0.5 lunch, 50 min/hr = 11-1.5-.5*50/60 = 7.5 eff hr/11 hr sh	68.18%	85.00%	57.95%

Availability means: availability of unit due to maintenance or other downtime. Use of availability means: percent use of available unit operation time.

[2] 24-hours per day, 365 days/year.

[3] Based on Table 1, Tier 1 LDDV from "MOBILE6 Estimates of Exhaust Emissions for 1994-and-later Light Duty Diesel Cars and Trucks" EPA, July 2001. Assumptions of 300hp and an average of 5 mi/hr.

Montanore Mine

Phase I Construction Mobile Source Diesel Combustion SO_2 Emissions

Note: 28.6% of total underground production estimates used as estimate, as is the underground percentage through the Libby portal during production.

Mobile Source	Typical Engine Model	Engine Horsepower (hp)	Number of Units	SO_2 Emission Factor (g/hp-hr)	Emission Factor Basis	Equipment Availability and Use of Avail [1]	Load Factor	Maximum 24-Hr Operating Schedule [2] (hr/day)	Maximum 24-Hr Emissions (lb/day)	Annual Operating Schedule [2] (hr/yr)	Annual Average Emissions (tpy)
UNDERGROUND											
Road Grader - 14H	Cat 3176DITA	220	1	0.7773	Manuf	57.95%	0.4	24	0.60	8760	0.11
Personnel Bus	Cat 3056 E	150	1	0.163	S-bal.	57.95%	0.4	6	0.02	2190	0.00
Personnel Transport	Cat 3056 E	150	5	0.163	S-bal.	57.95%	0.4	24	0.43	8760	0.08
Boss Buggy	Deutz BF4M 1013	150	5	0.17	Manuf	57.95%	0.4	24	0.45	8760	0.08
50 Ton Haul Trucks	Detroit DDEC Series 60	575	4	0.163	S-bal.	57.95%	0.4	24	1.32	8760	0.24
50 Ton Haul Trucks	Electric Motor on trolley with DDEC Series 40 for use off trolley line Detroit 706 LTE 81 kw = 110 hp 25% of time operating	110	4	0.163	S-bal.	57.95%	0.4	5	0.05	1825	0.01
26 Ton Haul Trucks	EJC 530 - Detroit Diesel Series 60	400	2	0.163	S-bal.	57.95%	0.4	24	0.46	8760	0.08
Face Shovel Broyt ED 100W	Volvo TWD 1240 VE	375	2	0.163	S-bal.	57.95%	0.4	3	0.05	1095	0.01
3-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.17	Manuf	57.95%	0.4	4	0.03	1460	0.01
2-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.17	Manuf	57.95%	0.4	4	0.03	1460	0.01
Bench Drill	Electric/Diesel Tram Deutz 1013	116	2	0.17	Manuf	57.95%	0.4	2	0.01	730	0.00
7 CY LHD	Toro 007 - Detroit Series 50	250	2	0.163	S-bal.	57.95%	0.4	24	0.29	8760	0.05
8 CY LHD	Toro 1400 - Detroit S 60	325	2	0.163	S-bal.	57.95%	0.4	24	0.37	8760	0.07
Equipment Tram Generator	300 hp motor on each carrier and gen set	600	1	0.163	S-bal.	57.95%	0.4	8	0.11	2920	0.02
Bolter	Deutz BF4M 1013	150	4	0.17	Manuf	57.95%	0.4	24	0.36	8760	0.07
Scissor Lift	Deutz BF4M 1013	150	3	0.17	Manuf	57.95%	0.4	24	0.27	8760	0.05
Bulk Emulsion Handler Slurry Face Loader	Deutz BF4M 1013	150	2	0.17	Manuf	57.95%	0.4	24	0.18	8760	0.03
Bulk Explosive Truck	Deutz BF4M 1013	150	1	0.17	Manuf	57.95%	0.4	24	0.09	8760	0.02
Water Truck	Deutz BF4M 1013	150	1	0.17	Manuf	57.95%	0.4	24	0.09	8760	0.02
Supply such as Normet	Deutz BF4M 1013	150	3	0.17	Manuf	57.95%	0.4	24	0.27	8760	0.05
Fork Lift	Deutz BF4M 1013	150	2	0.17	Manuf	57.95%	0.4	24	0.18	8760	0.03
Construction Truck	Deutz BF4M 1013	150	1	0.17	Manuf	57.95%	0.4	24	0.09	8760	0.02
Mechanic Truck	Deutz BF4M 1013	150	2	0.17	Manuf	57.95%	0.4	24	0.18	8760	0.03
Electrician Truck	Deutz BF4M 1013	150	2	0.17	Manuf	57.95%	0.4	24	0.18	8760	0.03
Fire Truck	Deutz BF4M 1013	150	1	0.17	Manuf	57.95%	0.4	1	0.00	365	0.00
Fuel/Lube Truck	Deutz BF4M 1013	150	1	0.17	Manuf	57.95%	0.4	24	0.09	8760	0.02
Concrete Transport	Deutz BF4M 1013	150	2	0.17	Manuf	57.95%	0.4	24	0.18	8760	0.03

Underground Equipment Total (tpy) **1.16**

Underground Maximum 24-Hour Total Emissions (lb/day) **6.38**

Notes:

	Use of Avail	Availability	Total Availability
[1] 11 hr/shift, 2 spd, 1.5 hr travel, 0.5 lunch, 50 min/hr = 11-1.5-.5*50/60 = 7.5 eff hr/11 hr shi	68.18%	85.00%	57.95%

Availability means: availability of unit due to maintenance or other downtime. Use of availability means: percent use of available unit operation time.

[2] 24-hours per day, 365 days/year.

Montanore Mine
Phase I Construction Mobile Source Diesel Combustion VOC Emissions
Note: 28.6% of total underground production estimates used as estimate, as is the underground percentage through the Libby portal during production.

Mobile Source	Typical Engine Model	Engine Horsepower (hp)	Number of Units	AP-42 VOC Emission Factor (g/hp-hr)	Emission Factor Basis	Equipment Availability and Use of Avail [1]	Load Factor	Escape Factor	Maximum 24-Hr Operating Schedule [2] (hr/day)	Maximum 24-Hr Emissions (lb/day)	Annual Operating Schedule [2] (hr/yr)	Annual Average Emissions (tpy)
UNDERGROUND												
Road Grader - 14H	Cat 3176DITA	220	1	0.19	Manuf	57.95%	0.4	1.00	24	0.15	8760	0.03
Personnel Bus	Cat 3056 E	150	1	0.4	Tier 2[3]	57.95%	0.4	1.00	6	0.05	2190	0.01
Personnel Transport	Cat 3056 E	150	5	0.4	Tier 2[3]	57.95%	0.4	1.00	24	1.05	8760	0.19
Boss Buggy	Deutz BF4M 1013	150	5	0.07	Manuf	57.95%	0.4	1.00	24	0.18	8760	0.03
50 Ton Haul Trucks	Detroit DDEC Series 60	575	4	0.4	Tier 2[3]	57.95%	0.4	1.00	24	3.23	8760	0.59
50 Ton Haul Trucks	Electric Motor on trolley with DDEC Series 40 for use off trolley line Detroit 706 LTE 81 kw = 110 hp 25% of time operating	110	4	0.4	Tier 2[3]	57.95%	0.4	1.00	5	0.13	1825	0.02
26 Ton Haul Trucks	EJC 530 - Detroit Diesel Series 60	400	2	0.3	Tier 2[3]	57.95%	0.4	1.00	24	0.84	8760	0.15
Face Shovel Broyt ED 100W	Volvo TWD 1240 VE	375	2	0.3	Tier 2[3]	57.95%	0.4	1.00	3	0.10	1095	0.02
3-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.07	Manuf	57.95%	0.4	1.00	4	0.01	1460	0.00
2-Boom Jumbos	Electric/Diesel Tram Deutz 1013	116	3	0.07	Manuf	57.95%	0.4	1.00	4	0.01	1460	0.00
Bench Drill	Electric/Diesel Tram Deutz 1013	116	2	0.07	Manuf	57.95%	0.4	1.00	2	0.00	730	0.00
7 CY LHD	Toro 007 - Detroit Series 50	250	2	0.4	Tier 2[3]	57.95%	0.4	1.00	24	0.70	8760	0.13
8 CY LHD	Toro 1400 - Detroit S 60	325	2	0.3	Tier 2[3]	57.95%	0.4	1.00	24	0.68	8760	0.12
Equipment Tram Generator	300 hp motor on each carrier and gen set	600	1	0.3	Tier 2[3]	57.95%	0.4	1.00	8	0.21	2920	0.04
Bolter	Deutz BF4M 1013	150	4	0.07	Manuf	57.95%	0.4	1.00	24	0.15	8760	0.03
Scissor Lift	Deutz BF4M 1013	150	3	0.07	Manuf	57.95%	0.4	1.00	24	0.11	8760	0.02
Bulk Emulsion Handler Slurry Face Loader	Deutz BF4M 1013	150	2	0.07	Manuf	57.95%	0.4	1.00	24	0.07	8760	0.01
Bulk Explosive Truck	Deutz BF4M 1013	150	1	0.07	Manuf	57.95%	0.4	1.00	24	0.04	8760	0.01
Water Truck	Deutz BF4M 1013	150	1	0.07	Manuf	57.95%	0.4	1.00	24	0.04	8760	0.01
Supply such as Normet	Deutz BF4M 1013	150	3	0.07	Manuf	57.95%	0.4	1.00	24	0.11	8760	0.02
Fork Lift	Deutz BF4M 1013	150	2	0.07	Manuf	57.95%	0.4	1.00	24	0.07	8760	0.01
Construction Truck	Deutz BF4M 1013	150	1	0.07	Manuf	57.95%	0.4	1.00	24	0.04	8760	0.01
Mechanic Truck	Deutz BF4M 1013	150	2	0.07	Manuf	57.95%	0.4	1.00	24	0.07	8760	0.01
Electrician Truck	Deutz BF4M 1013	150	2	0.07	Manuf	57.95%	0.4	1.00	24	0.07	8760	0.01
Fire Truck	Deutz BF4M 1013	150	1	0.07	Manuf	57.95%	0.4	1.00	1	0.00	365	0.00
Fuel/Lube Truck	Deutz BF4M 1013	150	1	0.07	Manuf	57.95%	0.4	1.00	24	0.04	8760	0.01
Concrete Transport	Deutz BF4M 1013	150	2	0.07	Manuf	57.95%	0.4	1.00	24	0.07	8760	0.01

Underground Equipment Total (tpy) 1.51
Underground Maximum 24-Hour Total Emissions (lb/day) 8.25

Notes:

	Use of Avail	Availability	Total Availability
[1] 11 hr/shift, 2 spd, 1.5 hr travel, 0.5 lunch, 50 min/hr = 11-1.5-.5*50/60 = 7.5 eff hr/11 hr shift	68.18%	85.00%	57.95%

Availability means: availability of unit due to maintenance or other downtime. Use of availability means: percent use of available unit operation time.

[2] 24-hours per day, 365 days/year.

[3] NO_x and HC Emission Factors estimated based on Table 7 of "Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition, NR-009c, EPA, April 2004.

[4] Based on Table 1, Tier 1 LDDV from "MOBILE6 Estimates of Exhaust Emissions for 1994-and-later Light Duty Diesel Cars and Trucks" EPA, July 2001. Assumptions of 300hp and an average of 5 mi/hr.

Montanore Mine
Phase I Construction Generator

Aggreko
1.0 MW
1622 hp

Pollutant	Emission Factor[1] (g/hp-hr)	Maximum Hourly Emissions (lb/day)	Annual Emissions[2] (tpy)
NO_x	6.4	549.26	100.24
CO	0.31	26.60	4.86
VOCs	0.19	16.31	2.98
SO_2[3]	0.163	13.99	2.55
PM_{10}	0.09	7.72	1.41
PM2.5	0.09	7.72	1.41

Notes:
[1] Emission factors supplied by Aggreko.
[2] Annual emissions based on 350 days per year of operation.
[3] SO_2 based on S-balance and 0.05% S fuel.

APPENDIX E

DEPOSITION REFERENCES

DOE/TIC-27601
(DE84005177)

Atmospheric Science and Power Production

Technical Information Center
Office of Scientific and Technical Information
United States Department of Energy

DEPOSITION AND RESUSPENSION

George A. Sehmel, Pacific Northwest Laboratory

12

12-1 INTRODUCTION

The transport of particles and gases from the atmosphere to environmental surfaces and from those environmental surfaces back into the atmosphere is the subject of this chapter. When mass is transported from the atmosphere to an environmental surface, the removal process is described as *deposition*. The transport from the environmental surface back into the atmosphere is known as *resuspension*. These two mass-transfer processes are important in minimizing airborne concentrations at breathing height (deposition removes airborne pollutants) or in predicting airborne concentrations arising from surface contamination (resuspension).

These mass-transfer processes are of most interest for noxious airborne pollutants such as plutonium, sulfur compounds, lead, arsenic, and other materials. Because these particles can be inhaled, the potential hazards of deposition and resuspension to man must be known and minimized if necessary. Determination of these hazards requires that airborne concentrations be predicted from validated models that describe the transport of toxic material downwind. Unfortunately man is most often exposed to the hazard of inhaling these particles in the bottom 2 m of the atmosphere. This region of the atmosphere is generally neglected by models used to simulate the downwind transport and diffusion of pollutants. This chapter demonstrates how this neglect has limited our predictive capability and summarizes reported values of air—surface exchange mass-transfer rates described by dry deposition velocities and resuspension rates.

Currently, deposition and resuspension models have equal applicability to both natural and man-generated particles and gases. We cannot distinguish between the mass transfer behavior of two different particles of different chemical composition or solubility. Most of our knowledge of particle behavior cannot even distinguish between the behavior of different particle shapes. To simplify the physics and mathematics so that the aerodynamic behavior of a particle can be described, we usually assume particles to be spherical. For various gases, deposition rates are a function of chemical reactivity and solubility. Deposition rates are influenced by water solubility over water surfaces or within plant surfaces.

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Although many experiments have been conducted to determine the physics of particle and gas deposition, the results from these field experiments have not been generalized even within an order of magnitude, because of experimental uncertainties and limited data. Most experiments either have not been conducted under completely controlled conditions or have possibly been interpreted by too simple theoretical models. In field experiments, to interpret or predict downwind concentrations at the ground, modelers have related the deposition removal rate to assumed atmospheric diffusion coefficients.

To interpret deposition measurements, the modeler either had to assume a deposition removal rate or had to specify a vertical diffusion parameter. Usually neither of these parameters was measured independently. Independent predictions of the deposition removal rate are presented in this chapter.

The reinsertion processes discussed here consider both resuspension and suspension. Resuspension describes material deposited from the atmosphere and then subsequently reentrained or resuspended into the atmosphere. Suspension describes the deposition of particles on a surface by some process, such as an industrial spill, and the subsequent insertion of these particles into the atmosphere. Since the combined processes are usually referred to as resuspension, this term will be used in this chapter to describe both resuspension and suspension. Another reason for referring to these two processes by one term is that at the present time we cannot distinguish between the subsequent behavior of particles deposited from the atmosphere or from an industrial spill. A complicating factor is that pollutant particles on the ground most probably lose their individual identity by becoming attached to host particles. When the pollutant particle is transported downwind, it is usually attached to this host particle (Sehmel, 1976b, 1978b) rather than being transported as a discrete pollution particle.

Resuspension occurs both as a result of wind and the mechanical disturbance of the soil (Hereim and Ritchie, 1976) but more readily by the latter. Mechanical stresses, such as walking or digging, can raise particles above ground level into the main airstream so that they can be more rapidly transported downwind than they could by general wind resuspension. Mechanical stress also adds more energy to the soil surface than simple wind resuspension so that the soil is more readily resuspended. On the basis of limited

data, some estimates have been made of wind-induced resuspension rates as well as mechanical resuspension factors. These values are discussed in Secs. 12-4 and 12-5.

Agricultural erosion studies are briefly reviewed even though they have limited applicability to respirable toxic particle resuspension since they investigate bulk transport by soil erosion. The results of agricultural research are reported (Skidmore and Woodruff, 1968) in terms of a soil erodibility index. For further information the reader is referred to Chepil whose many papers are listed by Orgill (1977). From these studies, predictions of average soil loss in a field can be estimated in units of surface depth loss per unit time.

Airborne soil can change or alter expected airflow characteristics at the air–surface interface because the energy exchange between air and airborne particles alters the wind speed as a function of height (Bagnold, 1941). This change in the wind-speed profile from a logarithmic distribution is not discussed here, however. Although a change in wind speed can occur for large airborne dust loadings, the effects on resuspension and deposition have not been quantified.

A summary of deposition and resuspension research has been published by Engelmann and Sehmel (1976). That volume, as well as this chapter and its references, will probably lead the interested reader to most published results on these topics.

12-1.1 Transport Models

Although both deposition and resuspension measurements have been made and some correlating bases exist for predicting mass transfer at the air–surface interface, prediction models need much improvement. Many models have been developed to describe the combined deposition, resuspension, diffusion, and transport of an airborne plume. However, insufficient and inadequate data are available to validate these models. Furthermore, most modeling work compares predictions from different models rather than attempts to validate individual models. These model comparisons do not significantly improve our predictive capabilities in describing downwind transport.

Multibox resistance models are often used as a mathematical convenience to simplify the continuum mass-transfer processes (Calder, 1961) by including an initial box in the lower 1 mm assumed in chemical engineering models and additional boxes for incremental distances above 1 mm. These models describe mass transfer within the air–surface interface in terms of mass-transfer resistances. These models have been developed by Bennett, Hill, and Gates (1973), Bennett and Hill (1975), Caporaloni et al. (1975), Garland (1976a), Liss and Slater (1976), Markee, Andrews, and Jubach (1977), Murphy (1976), Sehmel and Hodgson (1978), Slinn (1976a, 1976b, 1977), and Slinn et al. (1978).

Multibox models are used by ecologists interested in the effect of pollutants on plants rather than in its inhalation hazard to man. Boxes are used to describe different leaf areas, such as the stomatal resistance to gas mass transfer. In this case, increased gas mass transfer occurs during daylight while stomata are open; decreased gas mass transfer occurs during darkness while the stomata are closed.

An integration method has not been validated for summing deposition on individual plant leaves from the canopy top to bottom. The multibox models require that calculations of flux and concentration gradient equality be made at the interfaces between boxes, but data to validate these calculations are not available to establish reference points between the boxes.

Data gathered from the multibox models can be used to predict the effects of pollutants on vegetation and structural materials as well as on man. This chapter, however, is mainly concerned with predicting airborne concentrations that are potentially hazardous to man.

When multibox resistance models are applied to diffusion and transport models, usually only two boxes can be used: an upper box described by standard meteorological diffusion and a lower box described by either a deposition velocity or a resuspension rate. Unfortunately these models have not been validated. In the absence of validated models, predictions of deposition velocities and resuspension rates are those reported in current literature and summarized in this chapter.

12-1.2 Deposition Velocity

Deposition velocity is a mass-transfer boundary condition at the air–surface interface in atmospheric diffusion and transport models. It includes the multibox resistances describing the total mass-transfer effects within the lowest few meters of the atmosphere. Chamberlain and Chadwick (1953) defined the deposition velocity as the ratio of the deposition flux divided by the airborne pollutant concentration per unit volume at some height above that surface layer. Thus the deposition velocity is usually reported in units of centimeters per second.

Historically the deposition velocity, v_d, has been defined as a deposition flux, F, divided by an airborne concentration, χ. For a depositing polydispersed aerosol and sometimes for a monodisperse aerosol,

$$v_d = -\frac{F}{\chi} \tag{12.1}$$

(The minus sign is required since the flux downward is a negative quantity whereas the deposition velocity is defined as positive.) For monodispersed particles the deposition velocity, $K_{1\,m}$, is defined as

$$K_{1m} = -\frac{F}{C} \tag{12.2}$$

where C is the airborne concentration of monodispersed particles. The deposition velocity nomenclature K, rather

than v_d, reflects that deposition velocities are a function of particle diameter. The subscript 1 m indicates a reference pollutant concentration at a 1-m reference height.

For measurement of the airborne concentration of a pollutant required in Eqs. 12.1 and 12.2, a reference height of about 1 to 1.5 m is used for land surfaces, whereas 10 to 15 m is used for ocean surfaces. For all reference heights and upwind sources, the detailed physics required to describe the integrated mass transfer within these lowest layers is not known (Doran, 1977). However, approximations and predictions of deposition mass-transfer rates are given in Sec. 12-3.4.

12-1.3 Resuspension Coefficients

Resuspension was described in the early literature (Langham, 1971) by a resuspension factor, RF, which is the ratio of airborne contaminant concentration per unit air volume, χ, divided by the contaminant surface concentration per unit area on the ground, G:

$$\text{RF (units of m}^{-1}) = \frac{\chi\ (\text{airborne concentration, m}^{-3})}{\text{G (surface concentration, m}^{-2})} \tag{12.3}$$

The airborne concentration is measured at some height above the ground surface concentration sample. Neither the height of air sampling nor the depth of surface soil sampling is specified, although breathing height and a 1-cm depth sample in the ground might be used.

The magnitude of the resuspension factor, which has ranged in experimental studies from about 10^{-10} to 10^{-2} m^{-1} (9×10^{-11} to 3×10^{-4} m^{-1} for wind resuspension and 1×10^{-10} to 4×10^{-2} m^{-1} for mechanical stresses from man's activities), depends in part on the sampling techniques used to measure particle concentrations. The definition given to "surface concentration" must be precisely stated since the term can mean anything from the pollutant in the first millimeter depth in the soil per unit area to that in the first several centimeter depth per unit area. Similarly the definition of "airborne concentration" is not often precise because the measurement height above the surface is not specified. Different measurement heights and particle sizes will certainly change the resuspension factor.

As Langham (1971) noted, although the resuspension factor is useful as an index to relate air concentrations to surface concentrations, it is "aesthetically nauseating and simpleminded." One deficiency is that the airborne concentration is assumed to be related to the surface concentration on the soil at a person's feet rather than upwind. Another deficiency is that resuspension factors are applicable only for the conditions for which they were determined. At the present time no general method has been devised to extrapolate or to predict resuspension factors for any situation. Even the taking of average resuspension factors is a risky concept because of the many orders of magnitude uncertainty in the resuspension factor. A third deficiency is that most resuspension factors have not been determined under conditions in which the resuspension source characteristics were carefully controlled. Sources are usually not uniformly distributed across an area, and the particle size on the ground has not been known.

Unfortunately resuspension factors do not describe particulate resuspension rates nor can they realistically be used to predict downwind air exposure and ground deposition. For downwind calculations, resuspension rates and airborne particle concentration profiles are needed so that the resuspension term can be dimensionally consistent with particle diffusion deposition models. For use in these models, a group of suspension (resuspension) rates, S, must be evaluated with units of the fraction resuspended per unit time. Suspension rates, S, rather than resuspension rates, are determined experimentally. Thus the total resuspension rate S is

$$S = f(S_{air}, S_{salt}, S_{sc}, S_W, S_M) \tag{12.4}$$

The three modes of soil transport as a function of particle size are S_{air}, S_{salt}, and S_{sc}, where S_{air} is the suspension rate for particles moving in true airborne suspension, S_{salt} is the suspension rate for particles moving in saltation, and S_{sc} is the suspension rate for particles moving in surface creep. These three variables must be considered, although one may dominate, since soil particle movement occurs by different mechanisms (Bagnold, 1941, 1960) for different sized particles. Wind resuspension rates, S_W, from all three modes of transport and mechanically caused resuspension rates, S_M, must also be considered. Each S_i must be evaluated, and general correlations for the S_i's must be established before a reasonable model can be developed for predicting particle resuspension and translocation.

When the contaminant surface concentration is known, the upward resuspension flux can be determined by multiplying the surface concentration by the resuspension rate. Conceptually this calculation is simple. In reality the physics are complex. One complication arises in determining the surface contamination level. For example, assume that (1) the resuspension rate is constant and (2) the total loss to air is small. Even in this case resuspension fluxes could change with time since the surface contamination source could also change owing to washing, weathering, and penetrating more deeply into the soil. Consequently, depending on the soil depth used to define the source strength, widely different resuspension fluxes could be calculated. If the source strength is measured to include all contaminants below the surface, the calculated resuspension flux would remain constant. If only the surface contaminant is measured, the calculated resuspension fluxes would increase with time.

Conceptually, both resuspension rates and factors are related only to the contaminant that the wind stress can act

on, which might be within the top millimeter or so of a soil surface. However, to determine the contaminant surface concentration experimentally, the contaminant must usually be calculated as a function of varying sampling depths. Often only the top 1 cm of soil is sampled. This presents no problem if the contaminant is only on the top surface of that 1-cm section because only this portion can normally be resuspended. However, if the contaminant is uniformly distributed throughout the top 1 cm, the estimate of the pollutant available for resuspension is too large. Other experiments have evaluated contaminant surface concentrations at even greater depths.

This inconsistency in determining the resuspension factor is also caused by sampling all particle sizes. These sampling techniques distort resuspension physics because they ignore how airborne concentrations of a particular particle size are related to the contaminant surface concentrations in that same particle-size range on the ground surface.

12-1.4 Concentration Prediction Accuracy

Many models are used to calculate the downwind transport, diffusion, and deposition of particles and gases. In general, the transport—diffusion models can be modified to include the effects of surface mass transfer. Some of the modified models include Sutton's equations (Chamberlain, 1955), Pasquill's model (1962, 1974), Pasquill's equations (Brook, 1968), a Gaussian plume model using surface depletion (Horst, 1977a, 1977b), Gaussian plume models by others (Csanday, 1955, 1957; Van der Hoven, 1963; Trevino, 1972; Mills, Dahlman, and Olson, 1974; Scriven and Fisher, 1975; Shreffler, 1975; Amato, 1976; Overcamp, 1976; Travis, 1976; Healy, 1974, 1977a; Vögt, 1977; Davis, 1978), Slinn's theoretical models (1976a, 1977, 1978), and finite difference models (Draxler and Elliott, 1977). In addition, surface soil transport by saltation and surface creep has been considered by Amato (1976). These models will not be specifically described here, because there is much uncertainty as to which one, if any, of them has been validated.

Gaussian plume models have often been used to predict the transport of particles over great distances. These predictions are a function of the atmosphere diffusion coefficients. However, Crawford et al. (1977, 1978) and others point out that the experimental conditions on which atmospheric dispersion curves (Pasquill, 1974) were developed are often overlooked or neglected in such predictions. The experimental data used in the models to define these curves were gathered from near-surface release experiments conducted on a smooth (roughness coefficient of approximately 1 cm), flat area for distances of less than 1 km and sampling times of 3 to 10 min. Modelers, however, have forgotten or overlooked the tentative nature of these dispersion curves and have extrapolated the dispersion curves to elevated release heights and to distances of over 200 km from the source.

If the uncertainty in predicting from different diffusion and transport models were resolved, a recommendation for a validated model including air—surface mass transfer might be possible. Mathematical models inherently have levels of uncertainty attached to them (American Meteorological Society 1977 Committee on Atmospheric Turbulence and Diffusion, 1978). For highly idealized conditions (i.e., uniform terrain, steady meteorology, source and ambient parameters measured carefully by research-grade instruments), the observed maximum downwind ground-level concentration is expected to be within 10 to 20% of that calculated for a surface-level source and within 20 to 40% for an elevated source. A factor of 2 accuracy is the best that can be expected in most urban-scale dispersion model predictions. Additional but unspecified uncertainties are suggested when dry deposition and resuspension are considered in model predictions. In using Gaussian plume models, Crawford et al. (1977, 1978) suggested tentative accuracy statements in estimating airborne concentrations which were based largely on scientific judgment. However, there are not enough data on which to base a reliable statistical estimate of model predictions. Nevertheless, for a highly instrumented flat-field site from which previous data and meteorological and airborne concentrations are available, it might be possible to estimate the ground-level airborne concentration from a continuous point source at downwind distances of less than 10 km to within a factor of 0.2 for the plume centerline concentration.

The accuracy in predicting airborne concentrations is expected to increase as averaging times increase. For a specific hour and downwind receptor point, the accuracy depends on calculating the exact plume trajectory. For flat terrain, relatively steady meteorological conditions, and distances of less than 10 km, airborne concentrations for an individual case might be estimated to within a factor of about ±10. The ensemble of a large number of air concentration calculations for a specific receptor point compares favorably with the ensemble of air concentration measurements at that point. Accuracies are about a factor of ±4 for monthly and seasonal averages. For an annual average concentration estimate, the accuracy is about a factor of ±2 for distances of 10 to 100 km in relatively flat terrain.

For complex terrain, a few experiments indicate departures of more than a factor of 10 from the estimates of the Pasquill—Gifford dispersion curves. For the complex terrain situation, the data are insufficient to generalize the results and to document accuracy. When the effects of surface mass transfer are included in addition to diffusion calculations, there appears to be no valid model that could be recommended for complex terrain. Even models for flat terrain show uncertain predictions. Nevertheless, as models become validated in the future, data will be needed on which to base surface mass-transfer calculations. The published data for deposition and resuspension are the focus of attention in this chapter.

Although there is uncertainty at the present time as to which transport model to use, the user is required to base predictions on current models. To make matters more difficult, the user is often limited in the complexity of the model he chooses. Since most model users are not only limited by computer capacity but also by costs, model predictions using modifications of the Pasquill (1962) diffusion curves are often used.

12-1.5 Concentration Profiles

Rather than discussing each transport model separately (see Chap. 13), this chapter discusses only the expected air concentration profiles that models should predict. These profiles are the airborne pollutant concentrations as a function of height aboveground. Figure 12.1 shows idealized, two-dimensional, airborne pollutant concentrations as a function of height for four different situations. Part (a) of Fig. 12.1 shows airborne concentrations for resuspension from a local source. In this case airborne concentrations are maximum at ground level and decrease with height. Downwind from that local source, airborne concentrations change, as suggested in part (b) of Fig. 12.1, and show a depletion near ground level due to particle deposition. Obviously, large deposition rates produce more depletion than low deposition rates. For both high and low deposition rates, a maximum concentration occurs at some height above ground level.

This maximum airborne concentration at an elevated height is also typical of elevated pollutant releases. For example, part (c) of Fig. 12.1 shows airborne concentration profiles for an upwind elevated source for both unstable and stable atmospheres. In a stable atmosphere, there is minimal vertical mixing, and the airborne pollutant plume does not diffuse as rapidly.

Airborne pollutant concentration profiles resulting from an upwind surface release are shown in part (d) of Fig. 12.1 for equal total deposition. Both stable and unstable conditions are considered. Airborne concentrations at ground level are less for the unstable case since pollutants mix upward more rapidly than in a stable atmosphere.

These profiles can be modified by precipitation, as well as by dry deposition. Wet removal is discussed in Chap. 11. However, in an analysis of the hazards of respirable airborne pollutants, only dry deposition can always be relied on to remove airborne pollutants near an industrial

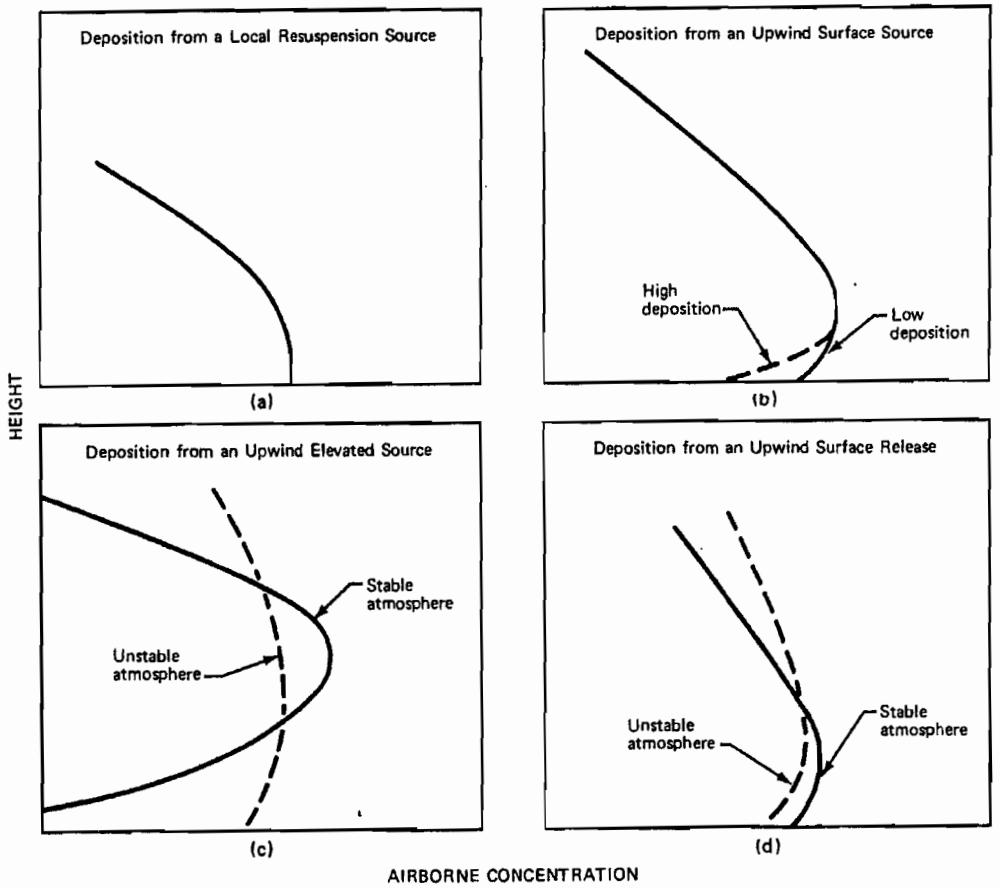

Fig. 12.1 Idealized airborne pollutant concentrations as a function of height for both resuspension and deposition sources.

released source. Dry deposition is always cleansing the atmosphere near ground level, whereas removal by precipitation is intermittent. Predictions (Marenco and Fontan, 1976) indicate dry deposition is more important than wet deposition for removing airborne pollutants from anthropogenic sources. This is not to contradict previous literature that suggested wet deposition was the primary removal mechanism for cleansing the atmosphere. Early literature indicating that wet deposition was more efficient referred only to the removal of radioactive particles from the stratosphere.

12-1.6 Respirable Particles

In air–surface mass-transfer exchanges, the most important particles to consider for both deposition and resuspension are those which can be inhaled and which potentially cause damage in the lung (see Chap. 16). In general, the respirability of a particle depends on its diameter. Particles less than 3.5 μm in diameter are most often considered to be respirable, but some data indicate that particles as large as 15 μm can be inhaled. The size of an inhaled particle determines where it will be deposited in the tracheobronchial tree and the relative hazard. Smaller particles are deposited in the alveoli; larger particles in the neighborhood of 15 μm or greater are denuded from the air by the nasal passageway.

Respirable particles (Volchok, Knuth, and Klemman, 1972) are the prime concern of this chapter; however, because pollutants are also transported downwind on nonrespirable particles, we will be looking at the air–surface mass transfer of both respirable and nonrespirable particles. The resuspension of pollutant particles transported on nonrespirable particles can occur if particles of respirable size become detached from the host particles and are resuspended (Sehmel, 1978a).

12-2 OTHER VARIABLES INFLUENCING AIR–SURFACE MASS-TRANSFER PROCESSES

The previous discussion has indicated many of the uncertainties and qualifications in accurately predicting airborne concentrations and mass transfer at the air–surface interface. Despite these uncertainties, much is known about mass-transfer processes. These processes are discussed in this chapter, but first we need to consider the other variables that influence mass transfer.

12-2.1 Soil Erosion

Because pollutant particles deposited on soil will probably become resuspended while attached to larger host soil particles, resuspension is also concerned with the physics of soil erosion. The main differences between research on noxious particle resuspension and that on soil erosion are in the mass of material transported and the particle diameters studied. Research into resuspension phenomena involves the study of transporting either toxic particles in the respirable diameter range or respirable particles on nonrespirable host soil particles. By contrast, research on soil erosion is directed toward determining bulk soil loss [densities ranging from about 0.9 to 2.8 g/cm^3 (Chepil, 1950b)].

Although resuspension rates and resuspension factors are probably influenced by different soil types, no data base exists for determining the effects of soil types or soil size distribution on resuspension. Nevertheless, some soil erosion concepts that might have the greatest influence on resuspension physics are discussed here.

Soil erosion becomes important to resuspension when vegetation surfaces are disturbed. Wind erosion alone was no problem in the Great Plains so long as native grasses protected the soil. It was after poor farming techniques that wind and drought transformed the Great Plains into a gigantic dust bowl in the 1930s.

The influence of wind alone must not be underestimated. It has been estimated that wind erosion of the total earth surface contaminates the atmosphere (Travis, 1976) with 10^4 to 10^6 tons of soil per day. This wind-blown soil accounts for approximately 9% of the total mass of atmospheric aerosol (Hidy and Brock, 1970).

Another factor to be considered in resuspension is total soil erosion over thousands of years, which can be estimated in many areas by the depth to which roots or rocks are exposed. In Greenland the average erosion in exposed areas was 9 to 37 m per thousand years (Judson, 1968). In vegetated areas, surface losses were less, only 3 m per thousand years and even less in Utah and California where root exposure depths indicate erosion between 0.02 to 0.1 m per thousand years. An estimate for continent-wide erosion is 0.024 m per thousand years. These average surface-depth erosion rates, ranging from 6×10^{-11} to 1×10^{-7} cm/s, correspond to an average resuspension rate of from 6×10^{-11} to 1×10^{-7} fraction resuspended per second for the top 1 cm of soil.

One problem in relating such soil erosion data to resuspension is that total erosion has usually been measured over wide source areas rather than as a function of small, local source areas. Although data on soil erosion and visibility (Hagen and Woodruff, 1973, 1975) indicate that erosion occurs in these local source areas, the data do not directly evaluate the resuspension rates of local contaminants.

Results from agricultural experience, however, can be used to suggest what might occur in resuspension processes. For "dry" soil with no vegetation, wind erosion occurs if either the wind speed is approximately 4 to 7 m/s, or greater, or the more than 65% of the soil particles are 2 mm or less in diameter (Van Doren, 1944). To reduce soil erosion, farmers alternate strips of crop and fallow land. This practice decreases soil erosion by controlling the abrasion of local soil by upwind soil. Alternating strips of cultivated land is more effective when crops are standing. For instance, standing wheat stubble is more effective than

flattened wheat stubble. Stubble in rows perpendicular to the wind direction also control wind erosion more effectively than rows parallel to the wind direction.

Soil erosion and, consequently, resuspension is not uniform across a field. Soil erosion rates are least near the windward side of the field and increase with downwind distance. Erosion rates increase with downwind distance because the abrasion of soil increases as soil is moved from upwind. This avalanching effect increases with downwind distance. Because of these soil erosion characteristics, the resuspension rates of respirable particles must be determined as a function of location in the field, height and density of land cover, and land usage.

Some data suggest that avalanching is a critical consideration in determining resuspension rates only for certain soil particle sizes. By a dry-sieving analysis of a 5-cm-deep surface soil sample, Chepil (1945c) found that erosive material less than 0.8 mm in diameter tends to accumulate at the lee sides of fields. A change in wind direction would, of course, cause a corresponding drift accumulation in the opposite direction. These phenomena suggest resuspension rates will change when the wind direction changes; however, theories are needed for predicting the attachment and movement of pollutant particles across fields.

Another limitation in using the results of agricultural erosion in resuspension studies is that they make no attempt to describe the respirable material that becomes airborne. Results on erosion are reported in terms of a wind erosion equation (Woodruff and Siddoway, 1965; Skidmore and Woodruff, 1968; Skidmore, 1976), which is a product of a soil erodibility index, a climatic index; a soil ridge roughness factor (Chepil, 1950a), the unsheltered field length, and an equivalent quantity of vegetation. The product of these terms is proportional to the annual soil loss in tons per acre or depth loss per unit time. This equation can predict soil losses up to about 340 tons/(acre · yr), which corresponds to about a predicted maximum average surface loss of 4 cm/yr or 1×10^{-7} cm/s.

Abnormal wind stresses, such as during a dust devil, also cause significant soil erosion, although their effects on the resuspension of pollutants have not been thoroughly investigated. During dust devils, soil concentrations of up to about 5 g/m^3 have been measured at heights 1 to 2 m aboveground (Sinclair, 1976). Even particles up to 350 μm in diameter have been transported. Although dust devils can transport large concentrations of soil, dust devils occur infrequently and therefore transport less soil than general dust storms. The physics of dust-devil transport are discussed by Sinclair (1976), and further discussion here will be omitted since the transport of toxic materials by dust devils had not been quantified experimentally.

12-2.1.1 *Soil Types.* Surface soils are described in terms of their particle diameter ranges—either sand, silt, or clay—and their mineral and organic matter content. Sand ranges from 50 to 2000 μm in diameter; silt ranges from 2 to 50 μm; and clay is less than 2 μm in diameter (Gillette, 1976). The percentage of sand, silt, and clay particles in the soil is referred to as the texture; the degree of aggregation of these materials is referred to as structure. In a non-aggregated soil a random distribution of individual particles exists, with smaller grains of silt and clay filling openings between larger grains of sand.

Soils consisting of a mixture of both coarse and fine particles are more easily eroded (Newman et al., 1976), as is the case for most sand dunes where the particle size ranges from 0.1 to 0.55 mm in diameter (Chepil, 1945b). Studies of soil mixtures have shown that particles less than 0.42 mm in diameter erode easily; those from 0.42 to 0.84 mm are more resistant. Material from 0.84 to 6.4 mm in diameter is highly resistant to erosion. A last classification includes all particles with diameters greater than 6.4 mm. When these largest particles erode, often 90% of the material moves within about 0.3 m of ground level.

12-2.1.2 *Surface Crust.* The resistance of the surface crust to soil erosion depends on the time since the last windstorm. If there has been a long interval between windstorms, a much higher wind speed is required to erode the soil since a surface crust can form which serves as a protective barrier against wind abrasion (Hinds and Sauer, 1976). This crust can be either biotic or clay cementation. If soil particles are eroded, the particles can cause abrasion of the surface crust and expose the more highly erosive soil beneath. This abrasive action is more rapid on the leeward side of a field, where the concentration of eroding particles is greatest.

A surface crust forms (Chepil, 1951b) when silt and clay particles smaller than 20 μm in diameter become dispersed during rain and subsequently dry. The crust depth seldom exceeds a thickness of about 0.2 cm. After a series of rains, the small silt and clay particles are carried downward, coarser particles being left at the top surface. Since some of these coarser particles can be subject to more rapid erosion even while the surface is drying, surface resuspension characteristics change continually, even for soils undisturbed except by natural phenomena.

12-2.1.3 *Soil Transport Classification.* Soil movement can occur on several scales. On a small scale, many sand grains tend to move simultaneously in a series of intermittent bursts confined to small surface areas. After movement ceases, the area remains quiescent until another short burst occurs (Sutherland, 1967). As wind speed increases, particle bursts become more active until particles are suspended and transported into the air. During these bursts, there may be either a gain or a loss of electrostatic charge on individual particles as they roll along the surface (Masironi and Fish, 1967).

Large-scale erosion has been described by three terms, which express continual soil movement as a function of surface stresses: saltation, surface creep, and suspension. Differences in motion between these three are gradual. How

the soil is transported depends on the diameter of the particle and the wind speed or wind turbulence. Saltation describes particles, ranging in diameter from about 100 to 500 μm (Newman et al., 1976), which jump or bounce within a layer close to the air–surface interface. Particles transported by surface creep range in diameter from about 500 to 1000 μm. The particles move by a sliding or rolling motion and are pushed along the ground by wind stresses and momentum exchange from the impact of smaller particles transported in saltation. Particles smaller than about 100 μm in diameter move by suspension. The amount of soil eroded by saltation, surface creep, and suspension varies greatly for different soils (Chepil, 1965; Oksza-Chocimowoski, 1976): suspension moves from 3 to 40% by weight, saltation 50 to 75%, and surface creep 5 to 25%.

12-2.1.4 *Saltation.* Of the three types of large-scale erosion just described, saltation (Chepil, 1945a) moves the greatest amount of soil. Saltating particles rotate at speeds from about 200 to 1000 revolutions/s and are ejected almost vertically into the airstream. The velocity of this vertical ejection is comparable to the friction velocity, u_* (Owen, 1964). While gaining considerably horizontal momentum from the wind, saltating particles descend with rather flat trajectories—at an angle of between 6 and 12° from horizontal—to strike the soil surface and thereby cause avalanching. After striking the surface, saltating particles either saltate again or cause surface creep. In either case, avalanching can cause some particles to move in true suspension.

Saltation motions indicate that sand is transported not by a diffusion process but rather through the impact of saltating sand grains, which act as projectiles. Since this motion cannot be described by eddy diffusion, existing meteorological transport and diffusion models have limited ability to describe the transport caused by saltating particles. Model development and validation are needed to describe saltation transport.

One way to minimize the eroding effects of saltation flows is to increase the widths of short vegetation stubble in a field (Chepil, 1945a). A 0.6-m-wide strip of short stubble can trap about 50% of saltating particles; a 3-m-wide strip can trap between 90 and 98% of saltating particles; and a 10-m-wide strip can trap over 99% of saltating particles. The height of the stubble also minimizes erosion. An 8-cm stubble traps about 60% of saltating particles, compared to a 15-cm stubble which traps about 85% of saltating particles.

Soil ridges are less efficient at controlling saltation than stubble of equal height. Because the ridges are widely spaced, saltating particles bounce off one or more times before finally being trapped within furrows. The collection efficiency of ridges depends on the ridge size (Chepil, 1945a). Ridges 6 cm high and 23 cm wide were found to be about 50% as effective as 15-cm-high wheat stubble in collecting saltating particles; ridges 13 cm high and 46 cm wide were about 77 to 83% as effective, and ridges 30 cm high were 85 to 92% as effective.

12-2.1.5 *Suspension.* Suspension describes the movement of soil particles below about 100 μm in diameter. This fine dust is lifted by the wind when saltating particles strike the surface. If it were not for saltating movement, this fine dust would not be eroded readily. Dust less than 50 μm and especially less than 10 μm in diameter is extremely resistant (Chepil, 1943) to wind erosion. However, when this fine soil is mixed with coarser particles capable of saltation, it is easily transported by suspension.

12-2.1.6 *Threshold Speed.* The wind speed necessary to begin soil erosion, termed the threshold speed, has been defined and depends on a complicated set of factors. One is whether a surface crust has formed on an exposed field (Chepil, 1945b). The wind speed required to initiate soil erosion in any given season is determined in part by this crust. The erosion of soil with a surface crust can be initiated by wind speeds of 6 to 13 m/s at an elevation of 0.3 m. Once that crust is broken, a bare field exposed to the continued action of wind erodes when the wind speed reaches 6 to 7 m/s at an elevation of 0.3 m.

According to Chepil (1945b), the lowest wind speed required to produce soil movement has been designated as the minimal fluid threshold speed, and the wind speed required to move the largest sand grains, as the maximal fluid threshold speed. Bagnold (1941) used the term "initial fluid threshold" speed as the wind speed required to initiate movement of the predominant sand dune material.

Determining threshold speeds is complicated by the movement of upwind saltating particles. During saltation the minimal impact threshold speed is the wind speed required to initiate soil movement by the force of descending soil particles carried in saltation rather than by direct surface wind stresses. After erosion has started, it will spread downwind by the bombardment of particles moving in saltation. The saltating particles cause movement in other parts of the field which under an equal air speed without bombardment would have remained at rest. A minimal threshold speed for a field depends on the minimal threshold speed for the most erosive upwind spots in the field. Thus the wind speed required to initiate soil erosion in a field of saltating particles is equal to the minimal impact speed rather than to the minimal fluid threshold speed.

Small threshold speeds occur for particles ranging in diameter from 0.1 to 0.15 mm. For smaller particle diameters the threshold speed increases with a decrease in particle size. For particle diameters larger than 0.15 mm, the threshold speed increases. For mixtures of soil particle sizes, the threshold speed is smaller than that required to erode only the largest particle. In other words the threshold speed increases directly with average particle size and decreases with a wider range of particle diameters in the soil (Chepil, 1943). Bagnold (1941) indicates that particles above approximately 100 μm will saltate and be carried

aloft only if the wind speed becomes significantly greater than the threshold speed.

12-2.1.7 *Horizontal Soil Fluxes.* The results of soil erosion rates are important to resuspension studies since pollutants are often transported on eroding soil particles. The results of this research are often reported in terms of a horizontal soil particle flux, with particular emphasis on the transport of larger particles. O'Brien and Rindlaub (1936) developed the original relationship between the amount of sand transported and wind speed. These measurements were made at Clatsop Beach at the mouth of the Columbia River. At this location the sand has a mean diameter of about 0.02 cm. Their results have been adjusted to the amount of sand drift, Q, in kg/(m width · h). Results show

$$Q = 0.79u^3 \tag{12.5}$$

for wind speeds (u in m/s) greater than 6 m/s at an elevation of 1.5 m. Bagnold (1941) found similar results for the movement of sand during dust storms in the Egyptian desert. For a mean sand particle diameter of 0.025 cm, the amount of sand transported is expressed by the relationship

$$Q = 5.2 \times 10^5 \, (u - u_T)^3 \tag{12.6}$$

where u is the wind speed in m/s at a height of 1 m and u_T is the threshold speed equal to 4 m/s. It is obvious from comparing coefficients that horizontal fluxes are site specific.

Both expressions show that the horizontal flux of sand is proportional to wind speed, u^3. Similar results are reported in the wind erosion equation developed by Chepil (1951a). In wind-tunnel experiments the soil movement rate was a function of the friction velocity, u_*^3. However, wind-tunnel results indicated the total horizontal flux of sand was a function of the friction velocity, u_*^5.

Although O'Brien and Rindlaud (1936) originally determined that sand movement was a function of wind, the concept was independently studied in more detail by Bagnold (1941) and Chepil (1951b). Bagnold, who did the more extensive early work, was concerned with deposits of individual nonadhering grains larger than about 80 μm in diameter. He conducted his research on Sahara sand. Chepil also studied soil erosion and focused on particles less than 0.4 mm in diameter. Thus both Bagnold and Chepil were concerned with the movement of nonrespirable particles rather than respirable particles. Their research is important, however, because respirable particles are also transported on nonrespirable particles. Sehmel (1978a, 1978c) has shown there can be a greater flux of airborne plutonium on nonrespirable particles than on respirable particles.

Building on the findings of these investigators, Hsu (1971) developed a correlation for predicting sand transport as a function of mean sand particle diameter for data published between 1936 and 1963. In this correlation the rate of sand transport is proportional to the Froude number, $Fr^{1.5}$. The Froude number, Fr, is given by $Fr = u^2/gD$ and represents the ratio of inertial force, u^2/D, to gravitational force. With this correlation between wind speed (u), gravitational acceleration (g), and the mean sand grain diameter (D), the horizontal soil flux in kg/(m · h) can be scaled.

12-2.1.8 *Sand Grain Models.* Wind stresses on individual sand grains have been estimated by several investigators through sand grain models. In the modeling studies, force balances, including frictional drag, form drag, gravitation, and the Bernoulli effect, have been considered (Akiba, 1975; Andres, 1972; Chepil, 1950a, 1959, 1965; Ford, 1957; Kawamura, 1975; Malina, 1941; and Slinn, 1976b). The theoretical models have limited applicability to resuspension physics over a wide surface area since model results require integration over the entire surface area, a procedure involving formidable uncertainties. In addition, models of surface forces on individual particles need some means by which to describe the effects of avalanching probabilistically. These models will not be described further in this chapter.

12-2.2 Airborne Soil Concentrations

Airborne dust loadings tend to modify the air–surface mass transfer and exchange processes. Airborne soil particles can interact with airborne pollutant material as well as modify air velocities and exchange processes. They can agglomerate with pollutant particles or can react chemically in gas–solid reactions. In either case, airborne pollutants can be modified in their physical and chemical structure while airborne. These modifications could lead to changes in the transport properties of the pollutant.

Experimental field measurements of airborne soil concentrations have been organized to show the volume distributions for particles of different diameters. The volume distribution is given by

$$\frac{\Delta V}{\Delta \ln D} = \frac{\pi D^4}{6} \frac{\Delta N}{\Delta D} \tag{12.7}$$

in cubic micrometers per cubic meter. The total airborne particle volume is the integral of Eq. 12.7. The total dust loading can be calculated from the total volume and average soil density; a density of 2 g/cm^3 was assumed.

The volume distributions to be discussed are shown in Fig. 12.2 for data obtained at the Hanford site near Richland, Wash. (Sehmel, 1975b, 1977a). The volume distributions are for wind erosion without mechanical disturbance in a semiarid area. Figure 12.2 shows the airborne volume distributions determined by two sampling techniques. Airborne particle volume distributions were determined with an optical particle counter for particle diameters smaller than 5 μm. The shaded area is the experimental range. The upper limit for this diameter range corresponds to the maximum dust storm condition mea-

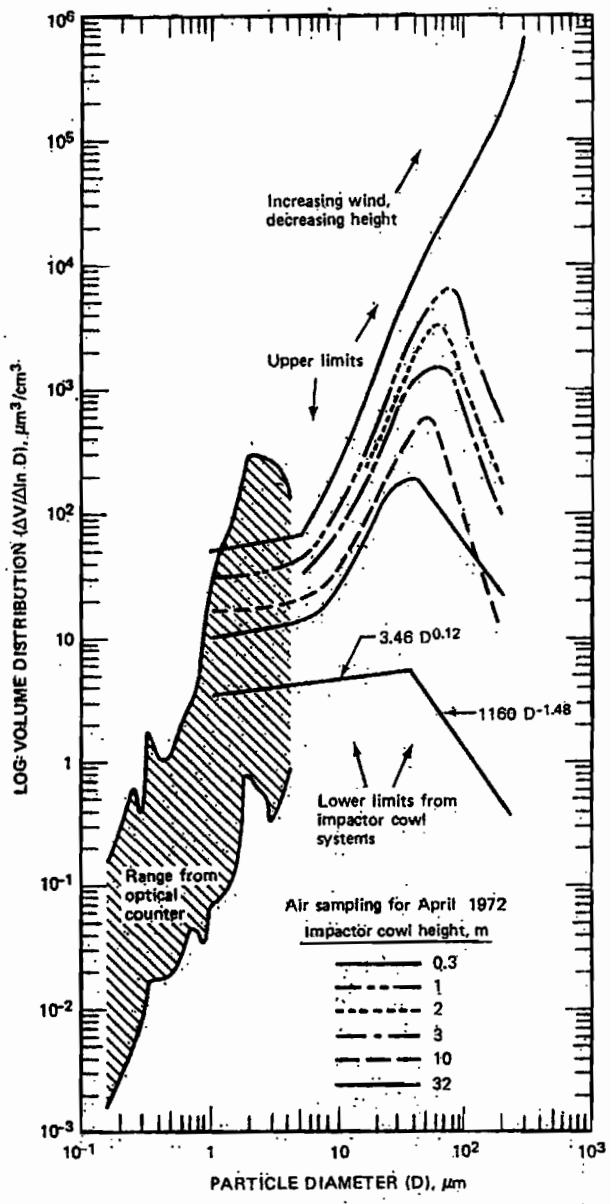

Fig. 12.2 Airborne particle volume distributions at Hanford, Wash.

sured, which corresponded to a maximum visibility of 1.4 km. The lower limit was for a clear day. Larger nonrespirable particles have been sampled with an opened-cavity collector (Sehmel, 1973a), and in this case the airborne volume distribution was a function of height. The maximum concentration measured was at 0.3 m above ground level. The volume distributions and concentrations decreased as the sampling height was increased.

Limits of airborne-soil mass loadings can be estimated from Fig. 12.2. For particle diameters less than 10 μm, the upper limit is 0.7 mg/m^3, and the lower limit is 7.7 μg/m^3. For particle diameters larger than 10 μm, the upper limit is 232 mg/m^3, and the lower limit is 20 μg/m^3. Thus a clean airstream might be one in which the airborne mass loading is in the neighborhood of 20 μg/m^3 (Sehmel, 1977b). In comparison, a dust loading of 110 mg/m^3 is barely tolerable for breathing (Stewart, 1967), whereas the maximum dust concentration measured in a dust devil is approximately 5 g/m^3 (Sinclair, 1976).

12-2.3 Deposition Variables

As Table 12.1 shows, many factors influence dry deposition rates: meteorological variables, properties of the depositing pollutant, and surface variables.

12-2.3.1 *Meteorological Variables.* One meteorological variable that influences dry deposition is aerodynamic surface roughness, z_0, which is used by micrometeorologists to assist in a description of the wind-speed profile above different surfaces. For near-neutral atmospheric stability, the logarithm of wind speed is described by (see Chap. 5)

$$u = \frac{u_*}{k} \ln \frac{z + z_0}{z_0} \tag{12.8}$$

where u = the measured wind speed
z = the measured height aboveground
u_* = the friction velocity
k = von Kármán's constant, which is approximately 0.4 (see Chap. 5)

For a surface of greater geometric roughness, the height is adjusted to a zero-displacement plane, d, within the canopy. In this case the relationship is

$$u = \frac{u_*}{k} \ln \frac{z - d + z_0}{z_0} \tag{12.9}$$

The researcher using these equations can adjust the quantities d and z_0 until straight lines are obtained on semilogarithmic paper. Thus these d and z_0 values have no physical meaning other than an empirical data fit. Often d is about three-fourths of the canopy height, whereas z_0 might range from 10^{-4} to 10^2 cm (flat plate with d = 0 to a forest with d = 7 m, respectively). As a rule of thumb, the friction velocity might be a few percent of the average wind speed (see Chap. 5).

The aerodynamic roughness height, z_0, is an extrapolated ordinate at the z intercept. Although z_0 is useful in micrometeorology for momentum transfer by the air, it is not known whether there is a difference between the aerodynamic roughness height for momentum transfer by air and roughness heights for particle and gas mass transfer (Brutsaert, 1975). Calculations of zero-plane displacement have the same unknowns as those for aerodynamic roughness. Zero-plane displacements for mass must be determined and compared to those for heat and momentum transfer.

In micrometeorology, diffusion parameters are used to describe the transport of pollutants even though the effects of vegetative or structural canopies on diffusion coefficients

TABLE 12.1 Some Factors Influencing Dry Deposition Removal Rates

Micrometeorology variables	Depositing material: Particles	Depositing material: Gases	Surface variables
Aerodynamic roughness	Agglomeration	Chemical activity	Accommodation
Mass transfer	Diameter	Diffusion	Exudates
Particles	Density	Brownian	Trichomes
Gases	Diffusion	Eddy	Pubescence
Heat	Brownian	Partial pressure	Wax
Momentum	Eddy equal to	in equilibrium	Biotic surfaces
Atmospheric stability	Particle	with surface	Canopy growth
Diffusion, effect of	Momentum	Solubility	Dormant
Canopy	Heat		Expanding
Diurnal variation	Effect of canopy on		Senescent
Fetch	Diffusiophoresis		Canopy structure
Flow separation	Electrostatic effects		Areal density
Above canopy	Attraction		Bark
Below canopy	Repulsion		Bole
Friction velocity	Gravitational settling		Leaves
Inversion layer	Hygroscopicity		Porosity
Pollutant concentration	Impaction		Reproductive structure
Relative humidity	Interception		Soils
Seasonal variation	Momentum		Stem
Solar radiation	Physical properties		Type
Surface heating	Resuspension		Electrostatic properties
Temperature	Shape		Leaf, vegetation
Terrain	Size		Boundary layer
Uniform	Solubility		Change at high winds
Nonuniform	Thermophoresis		Flutter
Turbulence			Stomatal resistance
Wind velocity			Nonbiotic surfaces
Zero-plane displacements			pH effects on
Mass transfer			Reaction
Particles			Solubility
Gases			Pollutant penetration and distribution in canopy
Heat			Prior deposition loading
Momentum			Water

are poorly known. This lack of knowledge about the air–surface interface is one limiting factor in applying mass-transfer boundary conditions to transport and diffusion equations. Because the effect of canopies on diffusion cannot be predicted, the assumption is usually that diffusion parameters, such as those of Pasquill, are applicable to all situations.

Another important meteorological factor is the effect of terrain on dry deposition removal. In the past, attempts have been directed only toward measuring mass transfer across a uniform terrain. However, it is rather difficult to find what might be called a uniform terrain in the world since it is the exception rather than the rule. Limited effort has been made to determine the effects of nonuniform terrain on air–surface mass transfer; they can be predicted only from models that have not been validated.

12-2.3.2 *Pollutant Properties.* The properties of the depositing material which influence deposition are shown in columns 2 and 3 of Table 12.1. The removal of particles from the atmosphere is accelerated by gravitational settling. The parameters that determine gravitational settling are particle diameter (squared) and particle density. Usually small changes in temperature and relative humidity hardly affect calculations of particle settling velocities; however, hygroscopic particles can absorb sufficient water to change the particle mass, density, and shape.

One important consideration seldom addressed in transport calculations is the effect of particle shape and size on airborne transport and surface mass transfer. The usual assumption is that particles are spherical. However, many particles released from industrial sources are neither spherical nor solid. For instance, fly ash can contain hollow spheres and aggregates of many smaller individual particles. Although attempts have been made to describe the settling velocities of aggregates, no general method exists to predict their settling velocities. Studies have shown that the settling velocity of aggregates can have a settling velocity as small as 0.01 of that for a solid particle of equal mass (Sehmel, 1956).

Another pollutant property of interest is the effects of diffusion on both particles and gases. For very small particles (diameters $<0.1\ \mu m$), the Brownian diffusion coefficient increases as the particle diameter decreases. In

the limit as the particle diameter decreases, the Brownian diffusion coefficient for a particle approaches that for a gas. Brownian diffusion is extremely important in the final stage of small particle and gas mass transfer. In fact, within 1 mm of the deposition surface, Brownian diffusion is more important than particle inertia, particle eddy diffusion, and gravitational settling in causing final deposition.

For larger particles (diameters >1 μm), eddy diffusivity becomes important in causing deposition, as does particle inertia and gravitational settling. For rough surfaces, particle eddy diffusivity cannot be predicted. However, for a smooth surface, Sehmel (1971) showed that an effective particle eddy diffusivity can be much greater than the eddy diffusivity of air momentum.

For very small distances close to a surface, the effective eddy diffusivity for a particle can be an order of magnitude greater than that for air momentum transfer. This effective diffusivity is caused in part by the inertia of a particle being approximately 10^3 greater than an equal volume of air. The magnitude of this increased diffusivity makes the uncertainty in deciding to use the diffusivity of momentum or heat at larger heights a minor uncertainty of only about 1.4 (Businger et al., 1971).

The atmospheric eddy diffusivity can also be altered by a forest canopy. The diffusivity must change as a function of height as canopy elements interact with particle and gas pollutants. Nevertheless, it is the combined effects of diffusion and gravitational settling which bring particles and gases down through the canopy; however, neither of these changes can be predicted at the present time.

Possibly the most important factors influencing gas deposition or mass transfer are gas solubility in water (either open water or water on vegetation surfaces) and gas concentration in the water built up from prior deposition (Whitman, 1923; Bird, Stewart, and Lightfoot, 1960). If the gas reacts in the water phase, there could be no back pressure or resistance to additional surface mass transfer. However, if the gas dissolves without irreversible chemical reaction in the water, mass transfer can decrease as the amount of material deposited increases. Thus the mass-transfer rates should be a function of gas solubility in water.

12-2.3.3 *Surface Properties.* Many surface variables affecting deposition are listed in column 4 of Table 12.1. These include the accommodation or adhesion of particles as they strike surfaces (Romney et al., 1963). For instance, if a particle strikes a sticky or wet surface, it would not be so quickly reentrained as if it had hit another less accommodating surface. Deposition can also be affected by changed canopy structure at strong wind speeds, as when grass blades bend from their vertical orientation in strong winds. The effects of wind speed on canopy geometry and subsequent changes in deposition cannot be predicted from experimental field data.

Deposition rates for gases could be strongly influenced by the physiological state of vegetation. Gas mass transfer in vegetation is a function of whether the stomata on the leaf surfaces are open or closed, i.e., open during the day and closed at night (Bennett, Hill, and Gates, 1973; Bennett and Hill, 1975).

Few data have been collected to determine the penetration of depositing pollutants through a canopy. In some field experiments the deposited pollutant has been collected only from upper surfaces of the vegetation canopy. Other experiments have shown a deposition flux to the underlying surface. In wind-tunnel experiments with simple surfaces, Sehmel and Hodgson (1978) have demonstrated that penetration is a function of wind speed, particle diameter, and canopy structure. However, there are too few data to generalize the relative canopy penetration during deposition.

12-2.4 Resuspension Variables

Probably even more variables influence resuspension than deposition. Many of these are listed in Table 12.2 under these classifications: particle properties, soil properties, particle–soil interaction, surface properties, topography, and meteorological variables. Some variables in each column are discussed briefly.

12-2.4.1 *Particle Properties.* One of the most important variables influencing resuspension is particle diameter, shown in column 1 of Table 12.2. When this variable is being considered, the question really is, "What does particle diameter mean in terms of resuspension source characteristics?" At the present time the effects of the diameter of deposited pollutant particles on resuspension cannot be predicted.

The complicating factor in determining source characteristics is that, since pollutants become attached to host surface soil particles, source characteristics must be determined by the pollutant's distribution on the host particle. The methods used to determine particle size distributions in collected soil samples can change the pollutant distribution and even the distribution of host soil particles. Changes in particle attachment, for instance, can be expected in either liquid or air elutriation. Rosinski et al. (1976) have shown that respirable particles are released when a particle is dropped into liquid. Sehmel (1978a) has shown that respirable particles are released when a soil particle is dropped on a solid surface. In both methods, smaller respirable particles are released from host soil particles.

12-2.4.2 *Soil Properties.* The properties of soil that affect particle resuspension are listed in column 2 of Table 12.2. An overriding factor is the soil moisture content. As long as soil is saturated, resuspension will not occur; as the surface layer dries, however, resuspension can occur. The increased resuspension rate with decreasing surface soil moisture content is unknown.

The size and distribution of soil particles also influence resuspension. Soils are usually classified by the diameter of the particles comprising them; silt, clay, and sand identify

TABLE 12.2 Variables That Influence Resuspension

Particle properties	Soil properties	Particle–soil interaction	Surface properties	Topography	Meteorological variables
Chemical reactivity	Moisture content	Attraction forces	Areas of erodible surface	Agricultural	Air density, affected by
Density	Ratio of erodible to nonerodible fractions	Molecular forces	Cohesiveness of particles	Broken	Humidity
Hydrophobic		Van der Waals forces	Binding action of materials	Desert	Pressure
Hydrophylic		Chemical binding forces (Valence forces)	Surface moisture	Diurnal	Temperature
Particle diameter	Soil-size frequency distribution	Electrostatic forces	Cover	Flat	Soil burden carried
Respirable	Specific gravity	Magnetic forces	Obstructions	Forested	Influence on air velocity
Nonrespirable	Structure	Capillary forces at the surface of aggregates filled with liquid	Roughness, large scale	Hills	Avalanching
Frequency Distribution	Organic matter	Chemical reaction	Mechanical turbulence	Humidity	Saltation
Shape	Lime content	Contact area effect on adhesion	Overall sheltering	Seasonal	Surface moisture content
Surface roughness	Texture	Particle shape	Roughness, small scale	Temperature	Dew
	Temperature	Particle size	Orientation of obstacles	Undulating	Frost upheaval
		Nature of particle and surface	Percent of area covered by nonerodible aggregates or obstacles	Uniform	Relative humidity
		Surface roughness	Sheltering of individual particles	Urban	Temperature
		Adhesion of agglomerates vs. individual particles	Stability of aggregates against abrasion and disintegration by moisture and weathering	Valley	Surface dry
		Crystallization of dissolved substances	Temperature	Water	Surface drying
		Deposition of suspended colloidal particle	Topographic features		Surface frozen
		Hardening binders	Broken		Wind speed
		Liquid bridges	Uniform		Wind removal forces
		Mineral bridges	Vegetative cover		Mean wind speed
		Relative humidity	Live vegetation		Frequency, period, and intensity of gusts penetrating to the surface
		Temperature	Plant residue		Transient and steady drag
		Time of contact			Vertical wind profile
		Viscous surface coating			Stability
					Vertical turbulent exchange
					Surface roughness
					Temperature stratification
					Wind direction

three types. Soil erosion and resuspension rates can be altered by the proportion of each type of soil and the abrading action of soil carried from upwind.

This alteration can also be a function of time. After precipitation and drying occur, a surface crust of salts can form. This crust tends to minimize soil erosion until it is broken by mechanical action or by the upheaval of soil caused by thawing and freezing (Caine and Morin, 1976).

12-2.4.3 ***Particle–Soil Interactions.*** Many interactions between particle and soil can influence the attachment of pollutant particles to host soil particles. These interactions

are listed in column 3 of Table 12.2. Although soil–surface interactions have been measured (Corn and Stein, 1965; Corn, 1966; Walker and Fish, 1965; Punjrath and Heldman, 1972a, 1972b) in laboratory experiments for very simple surfaces, the results cannot be generalized to the more complex interactions in the environment.

Researchers investigating resuspension can, however, use some information about soil erosion. For instance, even though the effects of surface properties on resuspension are unknown, the greater the resistance of the canopy to wind erosion, the smaller the resuspension from underlying soil. The experience of wheat farmers substantiates the fact that vegetation tends to decrease soil erosion. We also know that soil erodes least at the upwind edge of a field and that erosion increases downwind across the field, caused in part because of the avalanching effect by soil particles as they strike and abrade downwind surfaces. This avalanching effect, which fans out across a field, has not been addressed in the literature on resuspension.

Studies also determined that resuspension can occur from vegetation as well as from soil. For instance, Aylor (1976) determined that large numbers of particles were resuspended from corn. Similar work has been done by Chamberlain (1970, 1974, 1975), Heinemann, Vögt, and Angeletti (1976a), Heinemann et al. (1976b), and Peters and Witherspoon (1972).

12-2.4.4 *Topographical Variables.* Although little is known about the effect of regional topography on resuspension other than visibility differences caused by airborne dust (Orgill and Sehmel, 1976), the effect of topography may influence average resuspension rates. Most resuspension literature discusses only desert or semiarid areas, rather than humid areas. Soil erosion data apply primarily to agricultural areas.

Bagnold's (1941) studies of erosion in the Sahara Desert are typical of the bulk of literature on erosion. However, the studies have limited applicability to resuspension within most of the United States because sand from the Sahara Desert is made up of larger particles than sand found in most areas of the United States where resuspension might occur. Bagnold also reported that he saw sand moving so close to ground level during a dust storm that only a man's head and shoulders were visible above the dust storm. Particles moving in this fashion are clearly not respirable particles and not the principal concern in studies of resuspension.

Although some data on soil erosion in agricultural areas might be applied in resuspension studies, few data have been collected to assess the resuspension that can occur in urban areas. Some data do show (Newman et al., 1976) that material is "refloated" by traffic on city streets. These suspended materials are primarily abraded tire and pavement particles and recycling pollutant particles. Only limited data quantify the reflotation rate (Sehmel, 1973c); see Figs. 12.11 and 12.12 discussed in Sec. 12-5.3. However, sometimes this urban resuspension is discussed in the literature as fugitive dust. A review of the literature on fugitive dust emissions is not included here.

12-2.4.5 *Meteorological Variables.* Although many meteorological variables are assumed to influence resuspension, their effects have not, for the most part, been quantified. During the development of the meteorological field, emphasis was mainly directed toward describing transport and diffusion with a mathematical boundary condition, or black-box region, which described mass transfer at the air–surface interface. In this region, especially the last few millimeters from the surface, wind stresses can cause resuspension. A detailed description of the black box is normally, of necessity, neglected in model calculations of transport and diffusion above the air–surface mass transfer. As indicated in Sec. 12-2.3.1, the air–surface mass transfer is even neglected in the mathematical concept of friction velocity and aerodynamic surface roughnesses, which describe wind stress.

The physics of turbulent wind stresses next to the surface are still being studied. In the literature on fluid flow, an undisturbed laminar boundary layer is no longer considered to occur next to a smooth surface. Air turbulence always penetrates to the surface intermittently and unpredictably, especially over rough surfaces. Turbulence can penetrate in a burst directed toward the ground or in a small dust devil. The author has seen small dust devils, on the order of 10 cm in height and spaced about 1 m apart, resuspend zinc sulfide tracer from an asphalt surface. These dust devils may have been caused by solar heating rather than by turbulence from the average air speed.

12-3 DEPOSITION PROCESSES

Field measurements of plume depletion and particle and gas dry deposition velocities are summarized in this section. Deposition velocities and fractional plume depletion are considered because airborne pollutant plumes are depleted at the air–surface interface by the dry deposition of particles and gases.

One variable affecting deposition and plume depletion is the available surface area, which is always greater in a vegetative canopy. The increased surface area is described by a leaf-area index, i.e., the canopy projected leaf area divided by the ground area covered by a plant stem. Leaf-area indexes are about 0.5 for natural grasslands, up to 3 for irrigated and fertilized pastures (Knight, 1973), 3 to 5 for mature row crops, 4 to 6 for deciduous forests, and even larger for evergreen forests (Whittaker and Woodwell, 1967). The total area index for a forest, including trunk and branch area, can be as large as 10.

Although these surface areas are important in determining the deposition rates, the overall effects of surface area on deposition velocities and plume depletion have not been quantified. Since field results cannot be generalized, model-derived dry deposition velocities are recommended for meteorological transport and diffusion models.

12-3.1 Experimental Plume Depletion

Plume depletion of particles and gases by dry deposition processes can be either determined experimentally or predicted from theoretical diffusion and transport meteorological models; however, the data base is not satisfactory for either method. Existing experimental plume-depletion data, as a function of distance, are summarized in Table 12.3. Although meteorological models attempting to predict deposition should agree with the experimental data, the models often lack validation. Until validation occurs, there is little reason to select one predictive model over another. One stumbling block in validating the models is that the particle diameters used in the initial plume-depletion experiments were unknown or were not necessarily recorded in the literature. Since deposition velocities are a function of particle diameter, determining the diameter is crucial for validating transport models.

Experimental determinations have shown that a particle plume depletes with up to 97% of the particles being removed across a distance of 3200 m (Simpson, 1961), 65% between 45 and 91 m (Sehmel and Hodgson, 1976), and 80% at a distance of 200 m (Start, 1970a, 1970b). Data for iodine, a gas, indicate plume depletion is only up to 3% at a range of 380 m (Zimbrick and Voilleqúe, 1969). A comparison of these depletion percentages and the distances over which depletion occurred shows that these data cannot be generalized. This experimental data base is too limited to generalize plume-depletion characteristics for particles and gases. To predict plume depletion for other situations, transport and diffusion meteorological models must be used even though the meteorological models need extensive experimental validation.

12-3.2 Dry Deposition Velocities for Particles

The best existing method to predict plume depletion is by the particle dry deposition velocity. Dry deposition velocities for many materials and various deposition surfaces including soils are summarized in Table 12.4. In the table, the velocities for different materials are listed as a function of particle diameter. The results of studies in which particle diameters were not reported are arranged at the end of the table in alphabetical order by each investigator. If possible, the range of experimental deposition velocities for each experiment is presented rather than the "average" deposition velocities. This range is critical in emphasizing the uncertainties in many deposition experiments and in our ability to predict deposition mass-transfer rates. The deposition velocities reported range over 5 orders of magnitude from a minimum of 10^{-3} cm/s to 180 cm/s. It is expected, and is shown if known, that the deposition velocity is greater than the gravitational settling velocity, v_t.

Most data gained through field experiments, however, cannot be extrapolated to other situations because the variables have not been adequately controlled. At the present time, for instance, field deposition data do not differentiate between experiments as a function of any particle property other than particle diameter. Furthermore, deposition results are often reported when a particle diameter distribution was studied rather than a single or a narrow particle diameter range. Although we know that

TABLE 12.3 Experimental Plume Depletion as a Function of Distance

Depositing material	Particle diameter if specified, μm	Air speed, m/sec		Atmospheric stability	Deposition surface	Deposition distance range, m	Plume depletion, %	Deposition velocity, cm/s	Reference
		u	u_*						
Uranine	1 median	2.5–8.4			Sagebrush	200	22–32		Islitzer and Dumbauld, 1963
						400	10–54		
ZnS					Sagebrush	200	0–1		Nickola and Clark, 1976
						842	2.8–5.7		
Uranine	0.7	1.5			Sagebrush, 1.2–1.5 m high	45–91	65		Sehmel and Hodgson, 1976
ZnS					Sagebrush	200	19–45		Simpson, 1961
						800	40–82		
						1600	58–93		
						3200	78–97		
ZnS					Cheat grass	3200	70–75		Simpson, 1964
Uranine		3–8				To 200	80		Start, 1970a, 1970b; Van der Hoven, 1970
Iodine			0.4	Unstable	Pasture	100–380	3.0	1.0	Zimbrick and Voilleqúe, 1969
			0.6	Unstable	Pasture	100–380	1.1	0.7	
			0.6	Unstable	Pasture	100–300	1.1	0.6	
			0.6	Unstable	Pasture	100–380	1.0	1.2	
			0.4	Stable	Pasture	50–300	1.3	0.1	
			0.1	Stable	Pasture	50–100	0.7	0.2	

TABLE 12.4 Dry Deposition Velocities for Particles

Depositing material	Particle size if specified: Diameter, μm	Particle size if specified: Other	Air speed, cm/s: u	Air speed, cm/s: u_*	Atmospheric stability	Deposition surface	Deposition velocity, cm/s	Reference
Particles	0.03–30			10–200		Z_0 from 0.001–10 cm	10^{-3}–40	Sehmel and Hodgson, 1978
Pollen	20	v_t = 1.5 cm/s				Microscope slides in grassland	4.5 (3 × v_t)	Raynor, 1976
	32–35	3.3					9.9	
	90–100	20					60	
Pollen	20	v_t = 1.5 cm/s				Microscope slides in forest	1.5 (1 × v_t)	Raynor, 1976
	32–35	3.3					3.3	
	90–100	20					20	
Lycopodium spores	32		110–920			Glass plate	0.7–3.5	Gregory, 1950
Lycopodium spores	32	v_t = 1.4–2.1 cm/s	104–740	12–94		Grassland	0.7–3.5	Chamberlain, 1966
Lycopodium spores	32					Moss bags	9 × (grass v_d)	Clough, 1975
Oleic acid	0.5					Moss bags	15 × (grass v_d)	Clough, 1975
Uranine	2		10^2–10^3			Pine and oak shoots	0.003–10	Belot and Gauthier, 1975
	5						0.02–30	
	10						0.1–60	
Plutonium		0.3 MMD*				Tray	7.3	Stewart, 1963
		16–29 MMD					3.2	
Rhodamine B	0.8					Snow	<0.6–19	Nickola and Lee, 1975
ZnS	5 MMD					Snow	0–31	
ZnS	5					Sagebrush	1.5–5.4	Nickola and Clark, 1976
$CuSO_4$	3–7			8–34		Paper	0.005–0.06	Horbert, Vögt, and Angeletti, 1976
						Smooth metal	0.007–0.08	
						Rough metal	0.006–0.007	
						Grass	0.015–0.15	
						Clover	0.018–0.15	
						Soil	0.01–0.05	
ZnCdS	3	v_t = 0.13 cm/s				Artificial surface in forest	0.1–0.5	Fritschen and Edmonds, 1976
ZnS	2.5				Stable	Sagebrush	0.5	Simpson, 1961
Natural aerosol	1–10		600			Grass sward	0.8	Clough, 1973
Blowing field		<6 m, most ≈1 μm					9.8	Porch and Lovill, 1976
Plutonium		1–2 AMAD†	0.4			Leaf area	4×10^{-3}–8×10^{-3}	Cataldo, Klepper, and Craig, 1976
$Pu(NO_3)_4$		0.5–1.7	1			Single bean leaf	2.6×10^{-3}–2.7×10^{-2}	Craig, Klepper, and Buschbom, 1976
Pu compounds		0.8–1.8	1			Plant canopy	3.5×10^{-3}–1.2×10^{-2}	Craig, Klepper, and Buschbom, 1976
Uranine	<1					Sand	0.03–0.3	Islitzer and Dumbauld, 1963
^7Be	<1					Ocean with rain	<0.6–5.3	Silker, 1976
Au colloid	0.8					Bean leaf	4×10^{-3}	Vaughn, 1976
Particles	0.05–0.1			5.5–20		Field	Increases with u_*, 0.1–1.1	Wesely et al., 1977
Beta–gamma Kiwi effluent	Median	σ_g				Resin-coated tray at 0.8 m height at distance, m		Henderson and Fultyn, 1965
	0.003–0.6					4900	0.4–0.8	
	0.006	16				9800	2–85	

TABLE 12.4 (Continued)

Depositing material	Particle size if specified: Diameter, μm	Particle size if specified: Other	Air speed, cm/s: u	Air speed, cm/s: u*	Atmospheric stability	Deposition surface	Deposition velocity, cm/s	Reference
	0.1	8				39000	0.1–3	
	0.1–0.4					1220	0.2–0.4	
	0.6	4				1220	0.07–0.50	
	0.2–1.4					2440	0.8–110	
	0.02–0.2					9800	0.3	
	0.02–4					1220	0.4–2.5	
	0.4–6					610	7–110	
	0.1–8					1220	0.9–100	
	2.8	4				4900	0.3–3	
	2.7–6					2440	0.4–5	
	3.9	3				2440	0.03–3	
	2.3–4					1220	0.5–6	
	5	4				4900	48–180	
Pb, auto exhaust	Aggregated					Whole leaves	0.008–0.12	Little and Wiffen, 1977
						Leaf disks	0.001–0.17	
	Aggregated exhaust, 0.04					Moss bags	0.1–2	
	0.01							
						Bare soil	0.005–0.05	
						Filter paper	0.003–0.1	
						Moss bags near highway	0.7–39	
	Nonaggregated (aggregated)					Grass	0.13 (0.019)	
						Soil under grass	0.015 (0.007)	
						Bare soil	0.035 (0.008)	
						Grass and soil	0.14 (0.026)	
Trace elements						Filter paper at 1.5 m	<0.4–1	Cawse and Peirson, 1972
							0.05–4.8	Cawse, 1974
							<0.01–>3	Cawse, 1975
Trace elements						Filter paper at 1.5 m	0.06–13	Cawse, 1976
Na							0.2–4.3	
Mg							0.6–>3	
Al							0.9–2.7	
Cl							0.2–6.3	
K							0.6–13	
Ca							0.4–1.4	
Sc							0.6–2.5	
Ti							0.7–2.2	
V							0.2–<0.7	
Cr							0.6–6.8	
Mn							0.4–0.9	
Fe							1.0–2.5	
Co							0.3–1.9	
Ni							0.7–<2	
Cu							<0.6–1.1	
Zn							0.4–4.5	
As							<0.1–<0.6	
Se							0.1–0.6	
Br							0.1–2.6	
Rb							<0.9–3.0	
Ag							<0.3–1.1	
Cd							<0.4–>8	
In							0.3–>6	
Sb							0.06–<0.4	
I							<0.3–<2	
Cs							0.2–0.6	
La							>0.6–3.5	

(Table continues on the next page.)

TABLE 12.4 (Continued)

Depositing material	Particle size if specified: Diameter, μm	Particle size if specified: Other	Air speed, cm/s: u	Air speed, cm/s: u_*	Atmospheric stability	Deposition surface	Deposition velocity, cm/s	Reference
Ce							0.5–1.9	
Sm							0.6–4.1	
Eu							0.3–>2	
Th							0.7–2.2	
Trace elements						Open bucket	0.2–6.4	Crecelius et al., 1978
Cl							6.4	
K							2.6	
Ca							2.6	
Br							2.3	
Fe							0.37	
Mn							0.59	
Ti							0.67	
Cr							0.60	
Pb							0.38	
Se							0.24	
As							0.70	
V							0.24	
Cu							3.0	
Ni							4.0	
Zn							1.8	
^{7}Be							0.96	
RaB and RaC						Filter paper	0.05	Bullas published by Chamberlain, 1960
Field tests			Deposition increases with u	Independent of lapse rate				Convair, 1960
^{137}Cs						Water	0.09 ± 0.06	
						Soil	0.04 ± 0.05	
						Grass	0.2 ± 0.5	
						Sticky paper	0.2 ± 0.4	
^{103}Ru						Water	2.3 ± 1.0	
						Soil	0.1 ± 0.2–<0.6 ± 0.4	
						Grass	0.02 ± 0.8	
						Sticky paper	0.2 ± 2.0 ± 1.0	
^{95}Zr + ^{95}Nb						Water	5.7 ± 3.4	
						Soil	2.9 ± 2.7	
						Sticky paper	1.4 ± 0.7	
^{141}Ce						Sticky paper	0.7 ± 0.6	
^{127}Te, ^{129}Te						Sticky paper	0.7 ± 1.3	
Pb, auto exhaust						Teflon	0.29	Davidson, 1977
Pb				Light	Stable	Snow	0.16 ± 2.0	Dovland and Eliassen, 1976
Sulfate				Light	Stable	Snow	0.2–2.9	
Fission products						Desert vegetation	3	Fuquay, 1957
Fluorides						Forage	0.3 ± 0.02	Israel, 1977
						Vertical lined filter paper	0.49 ± 0.19	
Beta activity						Sticky plate	1.0	Makhonko, 1970
Mixed fission products						Grass	0.04 ± 0.3	Megaw and Chadwick, 1956
						Grass substrate	0.02–0.17	
						Filter paper	0.03–0.16	
Ba						Grass	0.001–0.003	
						Substrate	0.001–0.006	
Sr						Grass	0.002–0.004	
						Substrate	0.003–0.01	
Mixed fission products, Ba, Sr						Oats		
						Ears	0.001–1.2	
						Stalks	0.004–1.8	
						Water	Function of particle diameter	Möller and Schumann, 1970; Schumann, 1975

TABLE 12.4 (Continued)

Depositing material	Particle size if specified: Diameter, μm	Particle size if specified: Other	Air speed, cm/s: u	Air speed, cm/s: u*	Atmospheric stability	Deposition surface	Deposition velocity, cm/s	Reference
						Water	Function of particle diameter and u	Sehmel and Sutter, 1974
Pb						Pluviometer	0.13	Servant, 1976
Atmospheric fallout						Fallout collectors		Small, 1960
						Annual	0.5 0.9	
						Monthly	0.2 3.4	
Atmospheric fallout						Sticky paper	0.07	Stewart et al., 1957
RaD						Tank	0.05–0.5	Styro and Shalaveyus, 1966
Natural aerosol						Great Lakes	0.8 7.6	Whelpdale, 1976
Lead, bromine, zinc						Urban St. Louis, 1973	2.2 ± 1.4	Young, 1978
						1975	1.8 ± 0.7	

*MMD = mass median diameter.
†AMAD = activity median aerodynamic diameter.

particle diameter greatly influences deposition velocities, other variables such as wind speed do also. Convair (1960) has shown that field deposition velocities increase with wind speed, even though in these field tests the deposition velocities were independent of atmospheric stability. Sehmel and Hodgson's (1978) model supports these tests by predicting that deposition velocity is independent of atmospheric stability.

Determination of deposition velocities from artificial surfaces in the field presents other problems. Artificial collection surfaces, such as fallout collectors, are often used to determine deposition velocities because of the formidable task of determining deposition velocities in the field. For fallout collectors to be useful in estimating plume depletion, they should have many of the characteristics of the surfaces being simulated. However, when deposition is directly measured on environmental surfaces, the question always arises as to whether or not enough surface has been sampled to obtain a representative deposition sample. When vegetation is being sampled, the total deposition rates must be determined as a function of height throughout the canopy as well as on the soil surface below the canopy.

Although much deposition velocity data are presented in Table 12.4 for both artificial and natural surfaces, little is known about the relationship between deposition on fallout collectors and deposition on natural surfaces. Currently the results from fallout collectors indicate only changes with downwind distance and time rather than the total deposition on natural surfaces.

Diffusion and transport models have been used to infer deposition velocities from limited field data. Predictions from these models are suspect at the present time because so little is known about mass-transfer processes at the air–surface interface and about dispersion coefficients as a function of height. Until data are sufficiently defined for these parameters, the uncertainties inherent in making deposition velocity predictions from diffusion and transport models must always be considered. The uncertainties are present since even diffusion models without deposition have limited validation data, even to 10 km (Crawford et al., 1977, 1978).

12-3.3 Dry Deposition Velocities for Gases

Values for the deposition velocities of gases are summarized in Table 12.5. Gases are listed alphabetically rather than in the order of their measured deposition velocities because the range of deposition velocities in any experiment is so wide. In fact, uncertainties in the deposition velocities for a single field experiment can range at least 1 order of magnitude. Dry deposition velocities for all gases range 4 orders of magnitude, from 2×10^{-3} up to 26 cm/s, only 1 order of magnitude less than the range for particle dry deposition, which is from 10^{-3} to 180 cm/s. Thus the range of deposition velocities for gases is comparable to that for particles.

Reported deposition velocities measured in field experiments will be considered to show the great range even for individual gases. The deposition velocities for iodine and SO_2 have been studied extensively because these gases could be effluents from nuclear (iodine) and nonnuclear (SO_2) industries. Even though studied extensively, these deposition velocities are so widely scattered that they could not be confidently predicted. The deposition velocity of iodine ranges 3 orders of magnitude; from 0.03 to 26 cm/s; the deposition velocity of SO_2 ranges 2 orders of magnitude, from 0.04 to 7.5 cm/s.

Although the deposition velocity of particles cannot be predicted with certainty, there is some indication that the deposition velocities for gases may depend on atmospheric stability (Bunch, 1968). Whelpdale and Shaw (1974) have shown a dependency on atmospheric stability, but the uncertainties are not stated in the deposition velocities and an inconsistency in the data is unexplained. They report that the deposition velocities to grass and snow for neutral conditions are greater than those for stable conditions. However, the deposition velocity to a water surface for a neutral atmosphere is greater than that for a stable atmosphere.

12-3.3.1 *Water Solubility.* Some uncertainties about the deposition velocity for gases are a function of surface conditions. For example, some gases are more water soluble than others; other gases can react within the water phase. These differences in solubility can cause a gas back pressure or equilibrium gas pressure to develop at the receptor surface which can resist dry deposition from the atmosphere. Some of these gas transfer problems are considered for water deposition by Slinn et al. (1978). Hill (1971) has completed one of the more extensive experimental studies of gas mass transfer onto potential environmental surfaces. His data have been recalculated to determine the deposition velocities shown in Table 12.5.

12-3.3.2 *Gas Reactions.* An important uncertainty in predicting deposition velocities is the reaction of gases with condensation nuclei and other small particles in the atmosphere during transport. After reaction, the gas loses its identity and is transported as the host particle with which the gas initially reacted. Consequently mass-transfer rates will be altered rapidly as gases are modified while airborne. Once the gas has become attached to a particle, Brownian transport and the deposition velocity decrease because the Brownian diffusion coefficient of a particle is much less than that of a gas.

12-3.4 Predicted Dry Deposition Velocities

Sehmel and Hodgson (1978) predicted deposition velocities, $K_{1\,m}$, as a function of particle diameter from 10^{-2} to 10^{2} μm, of friction velocities from 10 to 200 cm/s, of aerodynamic roughness heights from 10^{-3} to 10 cm, of particle densities from 1 to 11.5 g/cm^3, and of atmospheric stabilities for Obukhov's lengths from −10 to +10 m (unstable and stable atmospheres, respectively). These predictions were based on wind-tunnel-derived correlations for surface mass-transfer resistances for depositing particles. Predictions indicate that deposition velocities can range over several orders of magnitude from about 10^{-3} up to 10 cm/s. Moreover, they increase as roughness height increases, usually as friction velocity increases, and they are nearly independent of atmospheric stability.

Since field deposition experiments abound in uncertainties, it is encouraging that deposition velocity predictions are in the same range as those determined in field experiments. The validity of the deposition velocity model was also supported in a field experiment (Sehmel, Sutter, and Dana, 1973). For a polydispersed aerosol the predicted deposition velocity of 0.17 cm/s compared favorably with the experimental measurement of 0.21 cm/s. Model predictions also indicate the functional dependency of deposition velocity on the several controlling parameters. For a concentration reference height of 1 m and a constant friction velocity of 30 cm/s, predicted deposition velocities, $K_{1\,m}$, are shown in Fig. 12.3 as a function of aerodynamic surface roughness and particle density. In all cases the predicted deposition velocities are greater than the particle's gravitational settling velocity, i.e.,

$$K_{1\,m} \geqslant v_t \tag{12.10}$$

The gravitational settling velocity increases proportionally with particle density and the square of particle diameter. Only in the particle diameter range from about 0.1 to 1 μm is the deposition velocity nearly constant for a selected surface roughness, particle density, and friction velocity. For particle diameters larger than about 1 μm, deposition velocities increase because of an increase in eddy diffusion and gravitational settling. For large particles, deposition velocities approach their respective gravitational settling velocity. The deposition velocity of particles less than about 0.1 μm increases with decreasing particle diameter because of Brownian diffusion. Figure 12.3 shows the lower limits for deposition velocities calculated only from Brownian diffusion. On the left-hand side of the figure, a lower limit is shown for distances of 1 cm and 0.01 cm. For the calculation of these lower limits, only Brownian diffusion was assumed to cause mass transfer below the respective distance, whereas both Brownian diffusion and atmospheric diffusion were assumed to cause mass transfer for greater distances. These lower limits are a function of each distance. Thus Brownian diffusion is a controlling factor. When the controlling diffusion distance decreases from 1 cm to 0.01 cm adjacent to the deposition surface, the lower limit for deposition velocities increases nearly 2 orders of magnitude. Obviously predicted deposition velocities for small particles are dependent on Brownian diffusion adjacent to the deposition surface.

Upper limits for dry deposition velocities are also shown in Fig. 12.3. For these calculations the surface resistance to mass transfer within 1 cm of the surface was assumed to be zero. Between 1 cm and 1 m, deposition velocities were calculated by including only atmospheric diffusion (Sehmel, 1970, 1973b) and gravitational settling. For particle diameters less than 1 μm, the upper limit is nearly constant and decreases from 1.1 cm/s at 1 μm to 1.08 cm/s at 10^{-3} μm. Calculations were simplified by using the ground surface area rather than the total canopy surface area as the deposition surface. For the upper limit, deposition velocities increase for particle diameters greater than 2 μm and approach their respective terminal settling velocity. However, most surfaces are not smooth, and there

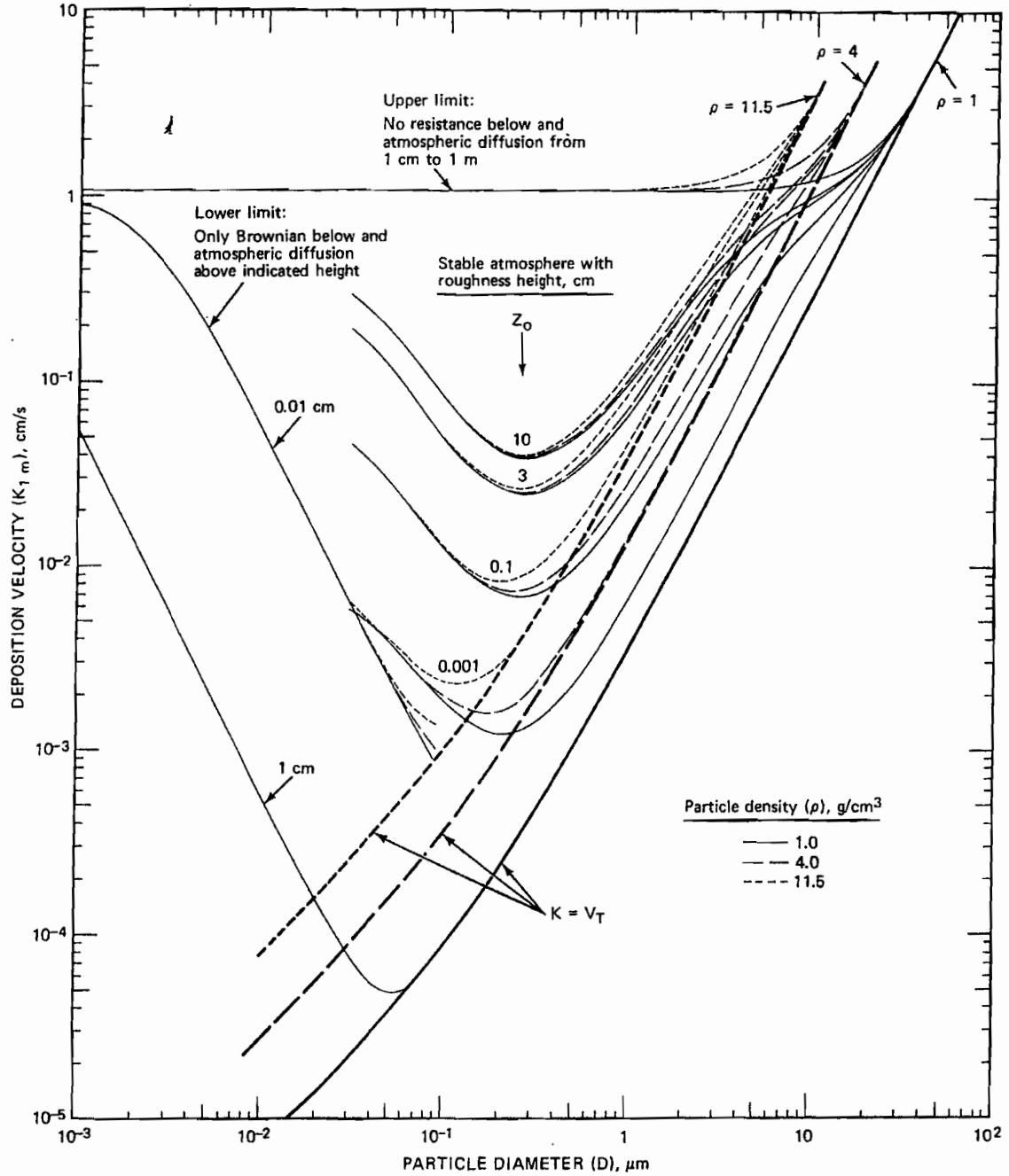

Fig. 12.3 Predicted deposition velocities at 1 m for $u_* = 30$ cm/s and particle densities of 1, 4, and 11.5 g/cm^3.

is greater surface area available in the canopy than on the underlying ground surface.

Figures 12.4 to 12.7 show predicted deposition velocities for a range of friction velocities and as functions of particle diameter, aerodynamic surface roughness, and particle density. Although predictions are shown only for a stable atmosphere, further predictions by Sehmel and Hodgson (1978) indicate that atmospheric instability increases the deposition velocities. The increase is small compared to the effects of particle diameter, friction velocity, and aerodynamic surface roughness. The deposition velocity of particles with diameters outside the range from 0.1 to 1 μm always increases with an increase in friction velocity. There is a minimum deposition velocity of 0.025 cm/s, however, which occurs for a friction velocity in the range of 20 to 30 cm/s. It is not known whether this minimum is physically real or only reflects uncertainties in the prediction techniques.

TABLE 12.5 Dry Deposition Velocities for Gases

Depositing material	Deposition surface	Deposition velocity, cm/s	Reference
Cl_2	Alfalfa	1.8–2.1	Calculated from Hill, 1971
CO_2	Alfalfa	0.3	Calculated from Hill, 1971
Dimethyl sulfide		Maximum rates	Judeikis and Wren, 1977
	Adobe clay soil	0.28	
	Sandy loam soil	0.064	
Fluorides	Forage	1.9 ± 0.5	Israel, 1977
	Vertical limed filter paper	0.36 ± 0.06	
HF	Field crops	3.1 ± 0.6	Israel, 1974
	Alfalfa	1.6	
HF	Alfalfa	3.5	Calculated from Hill, 1971
H_2S		Maximum rates	Judeikis and Wren, 1977
	Adobe clay soil	0.016	
	Sandy loam soil	0.015	
	Fe_2O_3	0.38	
^{85}Kr	Grass	Upper limit, 2.3×10^{-11}	Voilleqúe, Adams, and Echo, 1970
Iodine	Grass	Upper limit, 7.2 ± 0.9	
Iodine	Water	Increases with u, 0.2–1.2	Allen and Neff, 1975
Iodine	Activated-charcoal fallout plate		Bunch, 1968; Zimbrick and Voilleqúe, 1969; Markee, 1971
	Lapse	0.38–0.87	
	Inversion	0.03–0.30	
Iodine	Snow, neutral	0.34 median (0.085–0.41)	Bunch, 1968
Iodine	Open-range crested wheat grass	Median ± 1 σ in one test (range)	Bunch, 1968
	Growing	0.85 (0.033–4.2)	
	Damp	0.15 (0.033–0.66)	
	Damp	0.10 (0.019–0.225)	
	Dusty, dry	0.14 (0.13–0.15)	
	Dusty, dry	0.28, 0.54	
Iodine	Mixed pasture grass	Median ± 1 σ in one test (range)	Bunch, 1968
	Unstable		
	Dry	1.2 ± 1.6 (0.66–3.4)	
	Dry	1.0 ± 1.2 (0.42–3.2)	
	Growing	0.61 ± 1.6	
	Growing	0.79 ± 2.0 (0.15–6.2)	
	Neutral		
	Growing	0.79 ± 1.5 (0.14–2.0)	
	Stable		
	Green	3.3 ± 3.3 (1.4–26)	
	Freshly mown	1.7 ± 2.6 (0.21–6.2)	
	Freshly mown	0.41 (0.26–4.8)	

TABLE 12.5 (Continued)

Depositing material	Deposition surface	Deposition velocity, cm/s	Reference
	Freshly mown	0.23 (0.025–0.5)	
	Green	0.087 (0.021–0.41)	
Iodine	Grass	1.2–3.8	Chamberlain and Chadwick, 1953
Iodine	Grass	0.9–1.6	Chamberlain and Chadwick, 1966
Iodine	Field		Chamberlain, 1960
	$u_* = 15$ to 48 cm/s		
	$z_0 = 1$ to 5 cm		
	Soil + grass	1.1–2.6	
	Leaves	0.3–1.3	
	Paper leaves	0.6–2.0	
	Paper in Petri dish	0.3–0.9	
Iodine	Field grasses	0.3–0.6	Cline, Wilson, and Hungate, 1965
Iodine	Field		Convair, 1960
	Grass	0.5–4.0	
	Sticky paper	0.02–0.9	
Iodine	SL-1 accident		Gifford and Pack, 1962
	1 km	0.25	
	8.5 km	0.21	
	67 km	0.23	
Iodine	Pasture grasses	0.4–1.1	Hawley and Markee, 1964
Iodine	Routine releases, Hanford	2.8	Parker, 1956
Iodine	Grass ($u_* = 10$ to 69 cm/s)	0.3–2.7	Heinemann, Vögt, and Angeletti, 1976a
Iodine	Grass	0.12–8.0	Heinemann et al., 1976b
	Average dry	0.3–2.8	
	Average damp	0.9–6.3	
	Clover	1.0–4.2	
Iodine	Pasture grasses	0.2–1.2, function grass density	Markee, 1967
Iodine	Field	2.2	Megaw and Chadwick, 1956
Iodine with HIO_3, HIO_4, and organic iodides	Soil	2.7×10^{-2}	Miyamaga, Kasai, and Imai, 1973
	Sand	2.5×10^{-3}	
	Water	1.0×10^{-3}	
	"Leaf area"		
	Pine needle	2.0×10^{-3}	
	Leaf beet	2.1×10^{-3}	
	Spinach	1.1×10^{-3}	
	Chinese cabbage	7×10^{-4}	
Iodine	Windscale accident		Stewart and Crooks, 1958
	North England	0.30	
	South England	0.11	
Iodine	Grass	0.12–6.9	Vögt et al., 1973
Iodine	Mixed pasture grass	2.1, 2.4	Zimbrick and Voilleqúe, 1969
Methyl iodide	Pasture grass	1.4×10^{-4} – 2.4×10^{-3}	Atkins, Chadwick, and Chamberlain, 1967
Methyl iodide	Activated-charcoal fallout plate	0.12	Bunch, 1968
Methyl iodide	Mixed pasture grass	10^{-4}–10^{-2}	Bunch, 1968
Methyl iodide	Grass	(0.9% of that for molecular iodine)	Heinemann et al., 1976b
Methyl iodide	Mixed pasture grass	(<0.05% for molecular iodine)	Zimbrick and Voilleqúe, 1969
NO	Grass	Minus to 0.9	Droppo et al., 1976
NO	Alfalfa	0.1	Calculated from Hill, 1971
NO_2	Alfalfa	1.9	Calculated from Hill, 1971

(Table continues on the next page.)

TABLE 12.5 (Continued)

Depositing material	Deposition surface	Deposition velocity, cm/s	Reference
NO_x	Alfalfa and oats	0.5	Rasmussen, Taheri, and Kabel, 1974, calculated from Tingey, 1968
NO_x	Grass	Minus to 0.02	Droppo et al., 1976
O_3	Juniper bush	2.0	Calculated from Aldaz, 1969
	Alaska tundra	0.7	
	Sand or dry grass	0.5	
	Grass, Australia	0.4	
	Grass, Nebraska	0.2	
	Snow	0.1	
	Water, fresh	0.07	
	Water, sea	0.04	
	Water, distilled	0.02	
	Clean Mylar	0.002	
O_3	Grass	Minus to 0.03	Droppo et al., 1976
O_3	Grass	0.2–0.6	Droppo and Doran, 1978
O_3	Short dry grass	0.09–0.9	Calculated from Galbally, 1968
O_3	Near neutral		Galbally, 1971
	Dry soil mass		
	z_0 ~0.1 cm	1.3–1.7	
	z_0 ~0.4 cm	0.7	
	z_0 ~0.9 cm	0.9–1.2	
	Tundra		
	z_0 ~1 cm	1.4	
	Vegetation		
	z_0 ~1.6	0.7–1.5	
O_3	Soil 4% H_2O	1.76	Garland, 1976a
	Soil 27% H_2O	0.84	
	Peat 43%	1.39	
	Peat 74%	0.46	
	Grass	0.55	
	Grass + SO_2	0.74	
	Fuller's earth	0.73	
	Kaolin	0.49	
	Talc	0.33	
	Talc + exposure ozone	0.16	
	Sand	0.14	
	$CaCO_3$	0.22	
	$CaCO_3$ + SO_2	0.38	
O_3	Alfalfa	1.7	Calculated from Hill, 1971
PAN	Alfalfa	0.8	Calculated from Hill, 1971
SO_2	Grass	Minus to 2.4	Droppo et al., 1976
SO_2	Snow	0.07–0.38	Dovland and Eliassen, 1976
SO_2	Grass, $u_* = 0.07$ to 0.33 m/s	0.2–2.06	Garland et al., 1974
SO_2	Forest	<2	Garland, 1976a
	Fresh water	0.46	
	Short grass	0.55	
	Medium grass	0.77–1.9	
	Calcareous soil	1.1	
SO_2	Ice	0.10–0.17	Garland, 1976b
SO_2	Alfalfa	2.7	Calculated from Hill, 1971
SO_2		Maximum rates	Judeikis and Stewart, 1976
	Cement	2.5	
	Ready-mixed cement	2.0	
	Exterior stucco	1.8	
	Cement	1.6	
	Exterior stucco	0.86	
	Adobe clay soil	0.66	
	Sandy loam soil	0.65	
	Asphalt	0.04	
SO_2		Maximum rates	Judeikis and Wren, 1977

TABLE 12.5 (Continued)

Depositing material	Deposition surface	Deposition velocity, cm/s	Reference
	Adobe clay soil	0.92	
	Sandy loam soil	0.60	
	Fe_2O_3	3.9	
SO_2	Great Britain	1.3	Meetham, 1950
SO_2	B stability		Owers and Powell, 1974
	u = 2.6 m/s		
	Grass	0.5–0.7	
	Water	0.7–1.1	
	D stability		
	u = 5.2 m/s		
	Upwind grass	2.1–2.8	
	Hedge	4.9	
	To 30-m downwind hedge	1.4–1.8	
	D stability		
	u = 1.7 to 1.9 m/s		
	Grass	0.7 ± 0.1	
	Water	0.5 ± 0.1	
SO_2	Grass, $u_* = 0.2$ to 0.4 m/s	0.27–1.5	Shepherd, 1974
SO_2	Wheat	0.1–0.8	Unsworth and Fowler, 1976
	17-m forest	<0.6	
SO_2	Grass		Whelpdale and Shaw, 1974
	Lapse	2.4	
	Neutral	2.6	
	Stable	0.5	
	Snow		
	Lapse	1.6	
	Neutral	0.52	
	Stable	0.05	
	Water		
	Lapse	4.0	
	Neutral	2.2	
	Stable	0.16	
SO_2	Urban St. Louis		Young, 1978
	1973	3.8 ± 1.7	
	1975	6.2 ± 1.3	
ThB	Grass		Chamberlain, 1962
	Gas on 0.08-μm	2.6	
	nuclei	0.077	

Estimates of both the aerodynamic surface roughness height, z_0, and the air friction velocity, u_*, are needed to predict deposition velocities. Aerodynamic surface roughness is about 0.15 of the vegetation and physical roughness height (Plate, 1971). This simple relationship does not attempt to describe any changes in surface roughness which occur as the wind speed changes, e.g., a field of long grass becoming smooth during high wind speeds. The aerodynamic surface roughness of different surfaces at different wind speeds is given in Table 12.6, along with calculated friction velocities based on Eq. 12.8 for the average air speed at a height of 2 m. The magnitude of the friction velocity ranges from 3 to 15% of the air velocity at that height.

12-4 RESUSPENSION FACTORS

The resuspension factors reported in this section can be used to make conservative estimates of the potential hazards through inhalation. However, these factors were determined in experiments without differentiation between respirable and nonrespirable airborne particles.

12-4.1 Resuspension Factors Caused by Wind

Resuspension factors attributed to wind rather than to mechanical stresses are given in Table 12.7. These values have been either reported in or calculated from the

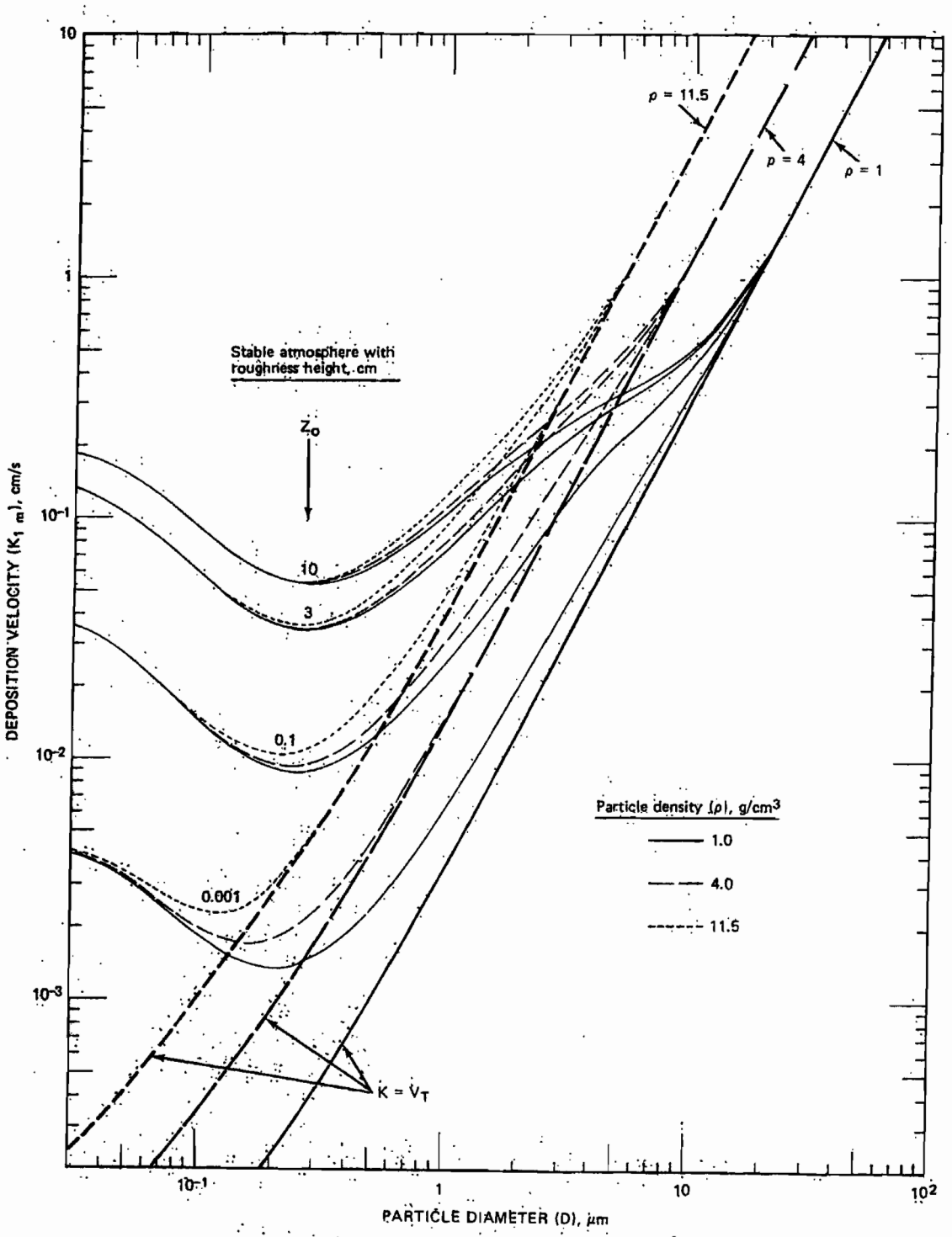

Fig. 12.4. Predicted deposition velocities at 1 m for u_* = 10 cm/s and particle densities of 1, 4, and 11.5 g/cm³.

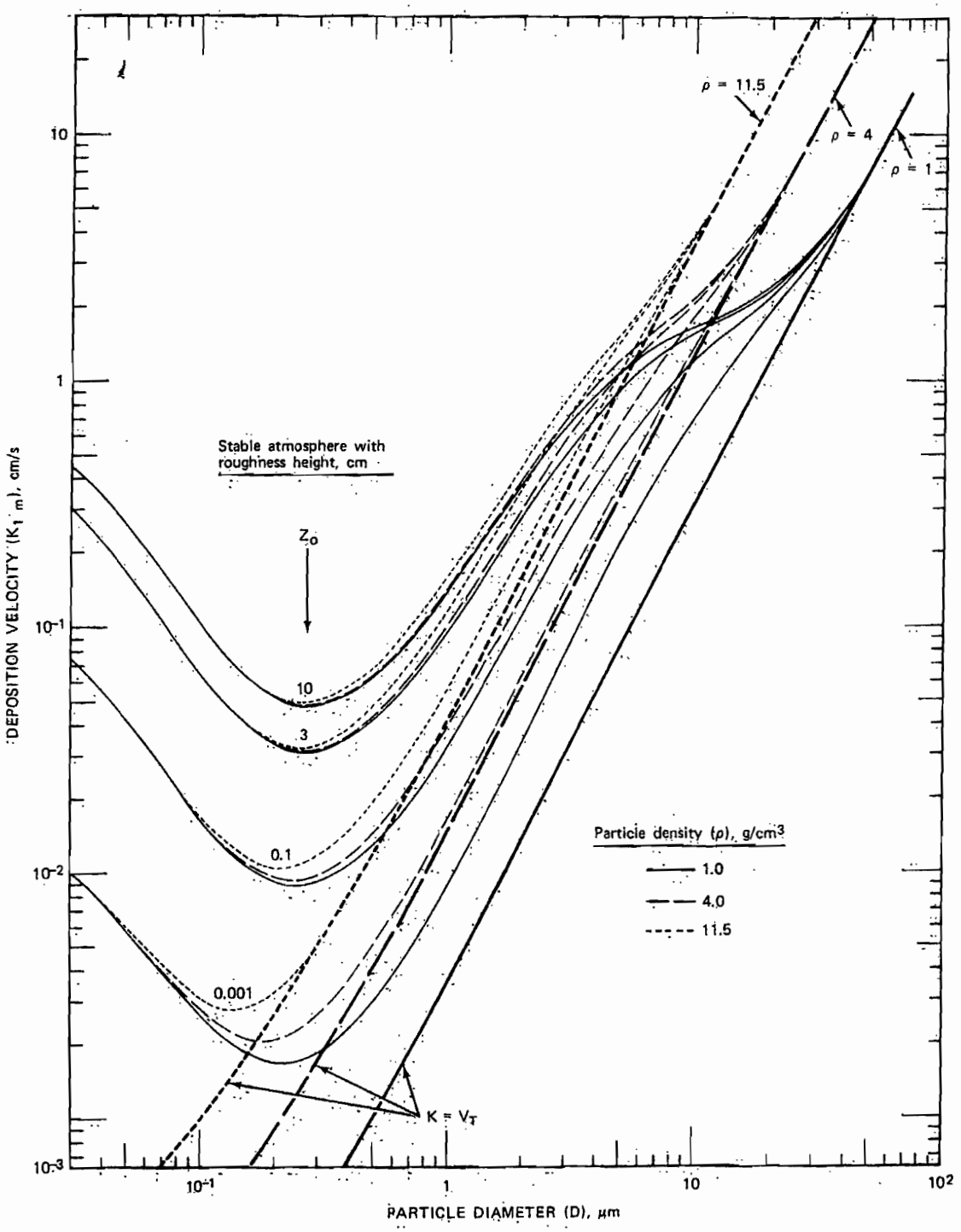

Fig. 12.5 Predicted deposition velocities at 1 m for $u_* = 50$ cm/s and particle densities of 1, 4, and 11.5 g/cm^3.

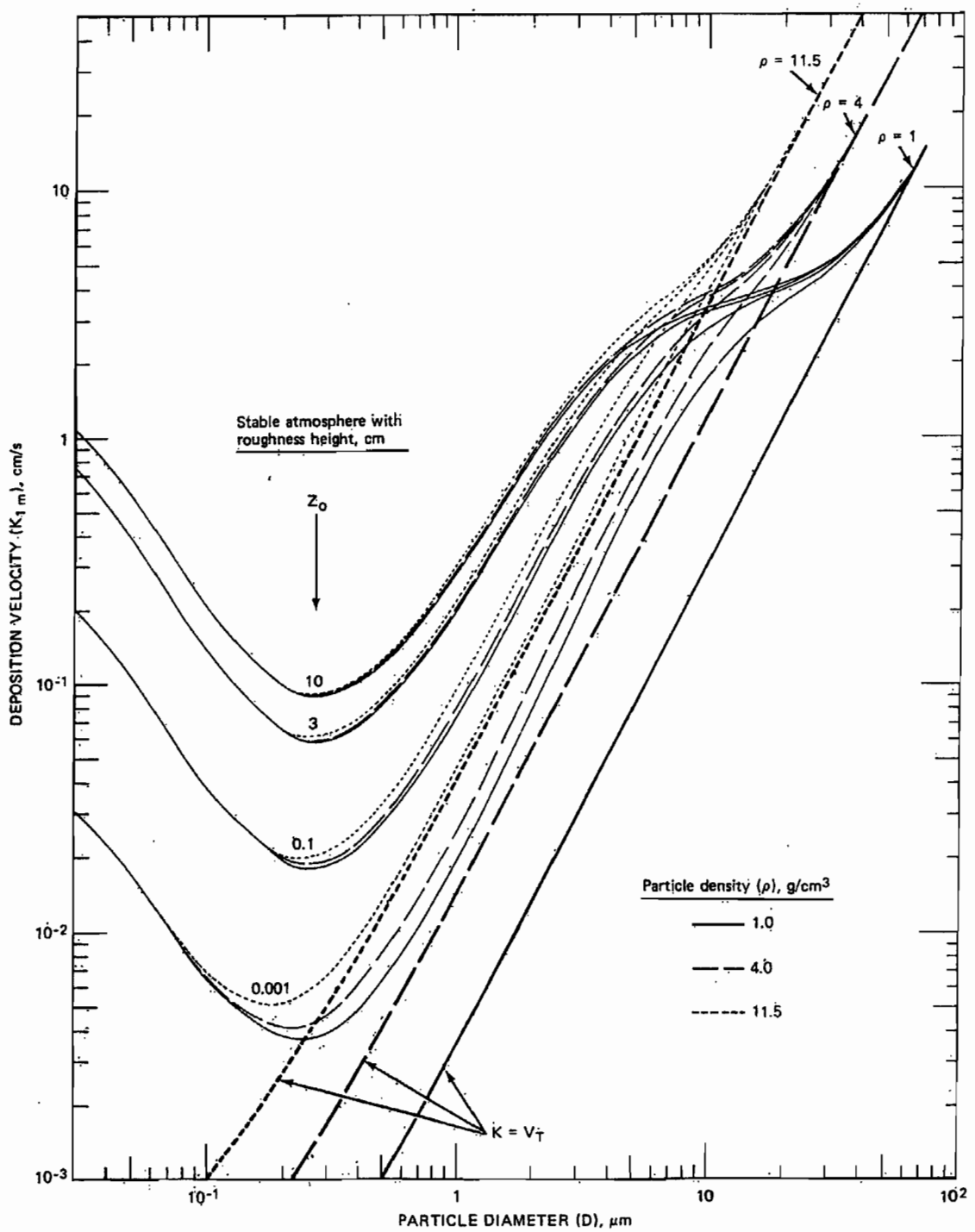

Fig. 12.6 Predicted deposition velocities at 1 m for $u_* = 100$ cm/s and particle densities of 1, 4, and 11.5 g/cm³.

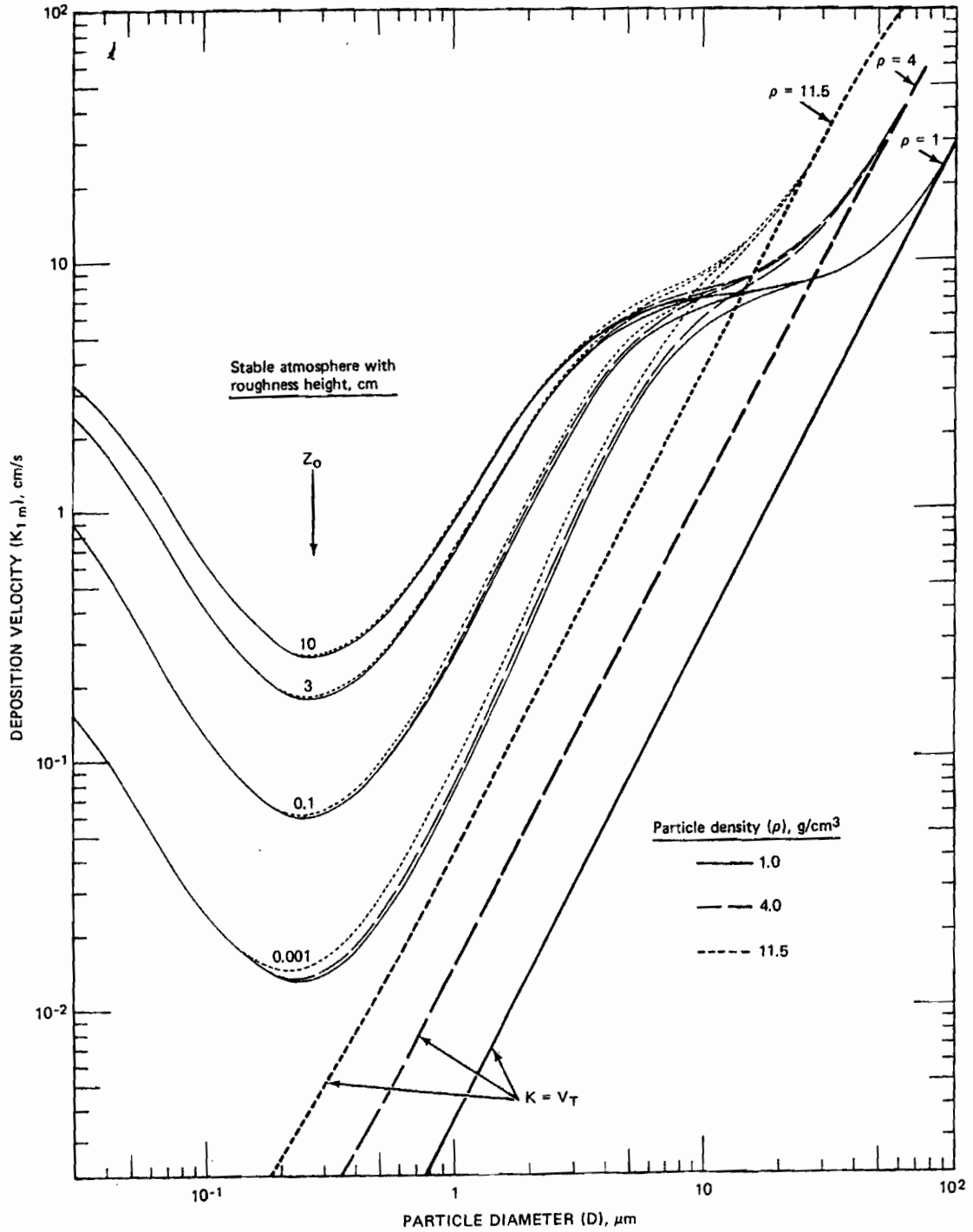

Fig. 12.7 Predicted deposition velocities at 1 m for $u_* = 200$ cm/s and particle densities of 1, 4, and 11.5 g/cm³.

TABLE 12.6 Calculated Friction Velocities for Typical Aerodynamic Surface Roughness Lengths

Surface	z_0, cm†	For u = 1 m/s at 2 m		For u = 5 m/s at 2 m		For u = 20 m/s at 2 m		For u = 40 m/s at 2 m	
		u_*, m/s	u_*/u, %	u_*, m/s	u_*/u, %	u_*, m/s	u_*/u, %	u_*, m/s	u_*/u, %
Smooth mud flats, ice	0.001	0.033	3.3	0.16	3.3	0.66	3.3	1.31	3.3
Smooth snow on short grass	0.005	0.038	3.8	0.19	3.8	0.76	3.8	1.51	3.8
Smooth sea	0.02	0.043	4.3	0.22	4.3	0.87	4.3	1.74	4.3
Level desert	0.03	0.045	4.5	0.23	4.5	0.91	4.5	1.81	4.5
Snow surface, lawn to 1 cm	0.1	0.053	5.3	0.26	5.3	0.97	4.9	2.10	5.3
Mown grass									
1.5 cm	0.2	0.058	5.8	0.29	5.8	0.98	4.9	2.32	5.8
3.0 cm	0.7	0.071	7.1	0.35	7.1	1.01	5.0	2.82	7.1
4.5 cm									
u_{2m} = 2 m/s	2.4	0.090	9.0	0.45	9.0	1.04	5.2	3.61	9.0
u_{2m} = 6–8 m/s	1.7	0.084	8.4	0.42	8.4	1.03	5.1	3.35	8.4
To 5 cm	1–2	0.075	7.5	0.38	7.5	1.51	7.5	3.02	7.5
		0.087	8.7	0.43	8.7	1.73	8.7	3.46	8.7
To 60 cm	4–9	0.102	10.2	0.51	10.2	2.04	10.2	4.07	10.2
		0.127	12.7	0.64	12.7	2.54	12.7	5.08	12.7
Long grass 60 to 70 cm									
u_{2m} = 1.5 m/s	9.0	0.13	12.7	0.64	12.7	2.54	12.7	5.09	12.7
u_{2m} = 3.5 m/s	6.1	0.11	11.4	0.57	11.4	2.27	11.4	4.54	11.4
u_{2m} = 6.2 m/s	3.7	0.10	10.0	0.50	10.0	2.00	10.0	3.99	10.0
Fully grown root crops	14	0.15	14.7	0.73	14.7	2.93	14.7	5.87	14.7

*Using 0.4 for von Kármán's constant and a zero-displacement length.
†Based on Priestley, 1959, and Slade, 1968.

literature. Data are listed in alphabetical order by author rather than in order of increasing magnitude because resuspension factors can range up to 3 orders of magnitude in one experiment. The range of resuspension factors rather than an average is listed to emphasize that most field experiments have been conducted with a resuspension source that was not uniform. In the field experiments, both large and small particles were resuspended, and particles were not uniformly distributed across the source. Because of these conditions, a single average resuspension factor for an individual experiment has an uncertainty of at least 1 to 2 orders of magnitude. In addition to this range in an individual experiment, resuspension factors range widely between experiments. In field experiments conducted to determine the influence of wind on resuspension, resuspension factors ranged from 10^{-11} to 10^{-4} m^{-1}, a range undoubtedly influenced by many of the factors presented in Table 12.2.

The extent to which wind speed influences resuspension factors is also indicated in Table 12.7. Iranzo and Salvador (1970) reported that airborne plutonium concentrations increased when wind speeds in Palmares, Spain, were above about 10 m/s. When the average wind speed is below 5 m/s, Stewart (1967) reported that resuspension factors tended to increase with wind speed to the third power. However, caution must be exercised in applying Stewart's data to other than slow wind-speed conditions because Sehmel (1977a) determined in tracer experiments that resuspension becomes more rapid for wind speeds above, not below, about 5 m/s.

Conceptually, resuspension factors should be a function of both the resuspension source area present and the sampling height. Experimentally there appears to be no significant difference between resuspension factors for a 1-m^2 source or a 1300-m^2 source. This anomalous behavior is unexpected, especially since little resuspension is expected for wind speeds less than 5 m/s.

That resuspension factors are also a function of the sampling height for airborne concentrations is borne out by the Maralinga trials data (Stewart, 1967) shown in Table 12.7. Airborne concentrations were found to decrease about 1 order of magnitude as the sampling height increased from 0.3 to 0.6 m.

Although a scientifically defensible basis for selecting a resuspension factor value is desirable, there is uncertain justification for the method of selecting reasonably conservative values of wind-induced resuspension factors. This uncertainty results from the fact that, in the original

TABLE 12.7 Resuspension Factors from Wind Resuspension Stresses

Location	Source material	Wind-speed dependency	Resuspension factor, m^{-1}	Reference
Nevada Test Site, Schooner	^{181}W		$10^{-7}-6 \times 10^{-5}$	Anspaugh et al., 1970
Nevada Test Site, GMX	Plutonium			Anspaugh et al., 1975
Near center			3×10^{-10}	
Near edge			2×10^{-9}	
New York, average air concentrations and surface deposition	Fallout		$5 \times 10^{-9}-2 \times 10^{-6}$	Calculated from Bennett, 1976
New York	^{238}U		5×10^{-8}	Calculated by Bennett, 1976
United Kingdom	^{238}U		5×10^{-9}	Hamilton calculated by Bennett, 1976
Palmares, Spain	Plutonium, 10-d samples	$u < 9.7$ m/s	$1.4 \times 10^{-9}-7.8 \times 10^{-6}$	Calculated from Iranzo and Salvador, 1970
Nevada Test Site, dusty rural air	Plutonium		7×10^{-6}	Langham, 1971
Hanford	Inert tracer, <1 μm	Increases	$1.7 \times 10^{-10}-2.7 \times 10^{-7}$	Sehmel and Lloyd, 1975
Rocky Flats	Plutonium		$10^{-9}-10^{-5}$	Sehmel and Orgill, 1973
Maralinga trials	Uranium	$u < 5$ m/s	3×10^{-4}	Stewart, 1967
	At 0.3 m height		1×10^{-5}	
	At 0.6 m height			
Paving stones	U_3O_8, 2-m^2 source	$u < 5$ m/s	$8 \times 10^{-9}-6 \times 10^{-6}$	Stewart, 1967
Sandy, desert grass	U_3O_8, 9-m^2 source		$1 \times 10^{-8}-5 \times 10^{-5}$	
Sandy soil with charred debris	^{210}Po	RF u^3		Stewart, 1967
	1-m^2 source	$u < 5$ m/s	$2 \times 10^{-9}-9 \times 10^{-6}$	
	1300-m^2 source	$u < 5$ m/s	$7 \times 10^{-8}-1 \times 10^{-5}$	
Monte Bello Islands, Hurricane trials	Fallout	$u < 5$ m/s		Stewart, 1967
	16-m source, lightly vegetated sand and rock		$1 \times 10^{-6}-1 \times 10^{-5}$	
	Near tower shot		$1 \times 10^{-8}-2 \times 10^{-7}$	
	Near road, no disturbance		$1 \times 10^{-8}-1.5 \times 10^{-6}$	
Cleared sandy soil	Yttrium chloride, aqueous solution	$u < 5$ m/s		Stewart, 1967
	1-m^2 source		$9 \times 10^{-11}-5 \times 10^{-8}$	
	9-m^2 source		$5 \times 10^{-10}-6.2 \times 10^{-7}$	

experiments, airborne concentrations were measured only under slow wind-speed conditions when resuspension factors are expected to be less, not in fast wind-speed conditions.

Anyone using Table 12.7, therefore, is advised to rely on site-specific data only from locations similar to the ones he is studying; they may be the best available estimates.

This recommendation carries a caveat, however. New York fallout data in Table 12.7 do not suggest that fallout resuspension factors should be used for determining local resuspension. The fallout resuspension factor was calculated by assuming that airborne concentrations were caused by resuspension rather than by stratospheric fallout. A "true" average resuspension factor for surface fallout might be less than the fallout range of 10^{-9} to 10^{-6} m^{-1} for New York. Therefore a better index of an average resuspension factor might be for ^{238}U resuspended from natural uranium in surface soil, where the resuspension factors range from about 10^{-9} to 10^{-8} m^{-1}.

12-4.2 Airborne Concentration Half-Life

The length of time since a contaminant was deposited is another variable that can influence airborne concentrations at a resuspension site. The change in airborne concentration with time near a resuspension site is reported in terms of an airborne concentration half-life, the apparent time required for the average airborne concentration to reduce to one-half of the original value. This length of time depends at least on average wind speeds and varies according to the availability of surface contamination to be resuspended. Although originally assumed to be constant, the half-life is now considered to change with time.

Half-lives summarized in Table 12.8 range from 35 d to years. This variability in the half-lives of even the same source material is probably caused by differences in the variable conditions, such as the wind speed, vegetative cover, time since deposition, and sampling technique at each test site. Some of the half-life data have been combined into overall models (Anspaugh et al., 1974;

TABLE 12.8 Half-Life Times for Decrease of Airborne Concentrations near Resuspension Sites

Location	Source material	Duration of experiment	Half-life for airborne concentration	Half-life for retention on foliage, d	Reference
Nevada Test Site, Plumbbob			Decreases with time		Shreve, 1958
Nevada Test Site	Plutonium	15 months	No change at 230 m		Healy, 1974; comparison of Wilson, Thomas, and Stannard, 1960, and Olafson and Larson, 1961
		5 to 15 months	Concentration decreased by only a factor of 1 to 10 at 760 m		
Nevada Test Site, Yucca Flat			Concentrations increased from 1956 to 1958		Mork, 1970
Russia	Alpha and beta	2 to 4 yr	Decreased 2 to 3 orders of magnitude		Izrael, 1971
		>4 yr	Practically constant		
Nevada Test Site, Plumbbob	Plutonium	1 to 5 months	35 d		Wilson, Thomas, and Stannard, 1960
Nevada Test Site	Plutonium		35 d		Langham, 1971
Nevada Test Site, Schooner	^{181}W	1.8 months	38 d		Anspaugh et al., 1973
Nevada Test Site, Baneberry	Gross gamma	9 months	76 d		Anspaugh et al., 1973
Hanford Area aged source	^{137}Cs, ^{238}Pu, ^{239}Pu	33 months	5 months to years		Sehmel, 1977a, 1977b
Hanford	Inert tracer	8 months	>8 months		Sehmel, 1977a
Rocky Flats after soil disturbance	Plutonium		9 months		Sehmel and Orgill, 1974
Field test	Solutions ^{85}Sr, ^{51}Cr, ^{214}Pb, and 1-μm-diameter polystyrene			49 in winter, 19 in summer (after 7 weeks)	Chadwick and Chamberlain, 1970

Kathren, 1968; Oksza-Chocimowoski, 1976, 1977), which are consistent with Shreve's (1958) original observation that the half-life decreases with time. These models describe an apparent half-life decrease with time by equations that describe different exponential changes (in half-life) with time.

The half-life may not always decrease with time. Half-lives for airborne concentrations at the Plumbbob nuclear test site were originally reported by Wilson, Thomas, and Stannard (1960) to range from 35 to 40 d. More recent results indicate a great uncertainty about these half-lives. In the original study starting in May 1957, the 35-d half-life was determined for an air sampling time period of less than 5 months. In the summer of 1958, Olafson and Larson (1961) measured airborne concentrations intermittently for times up to 15 months. In comparing the results from these two studies, Healy (1974) found that, during the 15-month time period, no appreciable change was reported in airborne concentrations within the data scatter at a site 230 m from the original test location. This result could indicate that resuspension was occurring at an average rate continuously during that 15-month period if the source were uniform with distance. At a site 760 m from the test location, airborne concentrations decreased by a factor of only 1 to 10. Thus changes in the air concentration may depend on proximity to the source and possibly local surface contamination levels.

Although the half-life concept appears to be questionable from experimental measurements of airborne concentrations, there is theoretical justification to expect some half-life to occur for resuspension source availability. Surface contamination will become attached to soil particles and migrate into the soil structure with time. This migration and coverage by vegetation and upwind soil erosion would make the source less available for resuspension. Data are insufficient, however, to characterize the half-life adequately. The possibility also exists that the surface contamination that does not migrate could become more readily available for resuspension by degradation processes, possibly biodegradation (Wildung and Garland, 1977) and solubility with time.

The half-life for airborne concentrations is also related to the changes in contamination on vegetation surfaces as a function of time, as experiments measuring the changes in surface contamination level on plant foliage have shown.

Chadwick and Chamberlain (1970), for example, reported a difference in the half-lives of pollutants retained on foliage between winter and summer months. As shown in Table 12.8, the half-life was greater during the winter.

12-4.3 Resuspension Factors Caused by Mechanical Disturbances

Resuspension occurs as a result of mechanical stresses caused by man's activities as well as by simple wind-induced resuspension. Resuspension factors measured during walking, working, driving, etc., are summarized in Table 12.9. Because of the range between the resuspension factors for each experiment, the results reported in each reference are listed together. Some judgment was used in arranging the data. In general, larger resuspension factors are listed first even if there are smaller values within the data grouping for the reference.

Resuspension factors for mechanical resuspension stresses range from 10^{-10} to 10^{-2} m^{-1}. This range overlaps the 10^{-11} to 10^{-4} m^{-1} values for simple wind resuspension. The upper range of resuspension factors for laboratory experiments is 2 orders of magnitude greater than the 10^{-4} m^{-1} for outdoor experiments.

Resuspension factors are included for both laboratory and outdoor experiments. Results from laboratory experiments are included since these data can be an index to an upper limit for resuspension factors in outdoor situations. In laboratory experiments the upper limit results from containing all resuspended particles in an unventilated room. Since, under these conditions, there is no wind to carry resuspended particles upward other than the air movement produced by the mechanical disturbance itself, data from laboratory experiments must be used cautiously in determining resuspension factors.

Much work remains in determining resuspension factors for both wind and mechanical resuspension (Sehmel, 1977a; Cowherd and Mann, 1976). Additional data are still needed for extrapolation or interpolation to determine the effect of the chemical or physical properties of resuspended material on resuspension. Few data in either Table 12.7 or 12.9 can be used to determine the effects of pollutant particle diameter on resuspension.

12-5 RESUSPENSION RATES

Sehmel (1977a) measured resuspension rates experimentally using tracer particles and mass balances of airborne tracer. In these experiments, resuspension rates were measured as a function of wind speed as well as respirable and nonrespirable particle diameters. Mechanical resuspension was measured for vehicular traffic on asphalt and an area vegetated with cheatgrass and for pedestrian traffic on asphalt. Sehmel's use of mass balance techniques to determine resuspension rates corrects a deficiency in early tracer resuspension data reported by Healy (1955, 1977b) and Healy and Fuquay (1958, 1959). In that early research, airborne concentrations of suspended tracers were estimated with air samplers located only at ground level. Later a diffusion model was used to calculate apparent resuspension rates. Since both methods can produce inaccurate data, only resuspension rates determined from mass balance techniques are discussed in this section.

12-5.1 Wind-Induced Resuspension

Airborne concentrations produced by wind stresses have been reported as a function of both wind speed and friction velocity. Resuspension data summarized in Table 12.10 show that air concentrations increase from the 1.1 to the 6.4 power of wind speed or friction velocity. However, agricultural studies by Bagnold (1941, 1960) and Chepil (1945a) indicate that fields erode as a function of air speed to the third power. The differences in rate might be attributed to the size of soil being considered in each study. The agricultural study focused on the erosion of nonrespirable particles, whereas the resuspension studies summarized in Table 12.10 focused on respirable particles. The wind speed on which airborne concentrations of respirable particles depend shows a great uncertainty.

Although the wind-speed dependency reflects resuspension physics, resuspension rates are needed for a boundary condition in meteorological transport models.

The particle resuspension rates summarized in Table 12.11 have either been calculated by using transport and diffusion models in interpreting measured concentrations at only one height or have been measured by integrating airborne concentrations as a function of height. Although the data determined from concentrations measured as a function of height with controlled resuspension sources are least questionable, resuspension rates for both experimental techniques range from about 10^{-12} to 10^{-4} fraction resuspended per second. This 8-order magnitude uncertainty is slightly less than the 11 orders of magnitude uncertainty for resuspension factors.

Average wind-induced resuspension rates for tracer particles have been measured (Sehmel, 1977a; Sehmel and Lloyd, 1975) for resuspension from three surfaces: an asphalt surface, a cheatgrass area, and an area lightly vegetated with cheatgrass and sagebrush. For average wind speeds of 1 to 4 m/s, wind resuspension rates for the asphalt surface ranged from 5×10^{-9} to 6×10^{-8} fraction resuspended per second. For average wind speeds of 1 to 5 m/s at the cheatgrass area, wind resuspension rates ranged from 5×10^{-9} to 6×10^{-8} fraction resuspended per second.

Resuspension rates (RR) of tracer particles from a lightly vegetated portion of the Hanford site are shown in Fig. 12.8. The rates are for submicrometer particles as deposited, and they are listed as a function of aerodynamic particle diameter when resuspended. The rates ranged from about 10^{-11} to 10^{-7} fraction resuspended per second.

TABLE 12.9 Resuspension Factors from Mechanical Resuspension Stresses

Location	Source material	Resuspension stress	Resuspension factor range, m^{-1}	Reference
Unventilated room	Beryllium	Vigorous sweeping	1×10^{-2}–4×10^{-2}	Mitchell and Eutsler, 1967
Small unventilated room	Alpha floor contamination	People walking	3×10^{-4}–2×10^{-2}	Calculated from Brunskill, 1967
Changeroom with no ventilation	Alpha on coveralls	Two to four people changing coveralls	$<2 \times 10^{-4}$–1.7×10^{-2}	Calculated from Brunskill, 1967
Changeroom, concrete floor, 9 air changes/h	10% "loose" alpha floor contamination	Four to six people moving in room	2×10^{-4}–3×10^{-3}	Brunskill, 1967
Simulated work	Asbestos contaminated coat	Machining operations	1.2×10^{-3}–5.3×10^{-3}	Carter, 1970
		Stacking sheets	2.0×10^{-3}–4.2×10^{-3}	
Room, concrete floor	Plutonium facility	No circulation	1×10^{-5}–2×10^{-4}	Glauberman, Bootmann, and Breslin, 1967
		Fan air stress	3×10^{-4}–3×10^{-3}	
		Fan and dolly movement	4×10^{-3}–1.5×10^{-2}	
		No circulation after tests	5×10^{-4}–1×10^{-3}	
Room, concrete floor	Uranium facility	No circulation	7×10^{-5}–4×10^{-4}	
		Fan air stress	3×10^{-5}–2×10^{-4}	
		Dolly movement	1×10^{-4}–2×10^{-4}	
		Fan and dolly movement	2×10^{-4}–1×10^{-3}	
Maralinga trials	Fallout	Road survey, at 1–2 d	$<1 \times 10^{-8}$–$>2 \times 10^{-6}$	Stewart, 1967
		Cab landrover, 5th h	6.4×10^{-5}	
		Cab landrover, 8th h	2.5×10^{-5}	
	Uranium	Dust stirred at 0.3 m height	1×10^{-3}	Stewart, 1967
	Plutonium	Vehicle dust at 0.3 m height	3×10^{-7}–7×10^{-4}	
		Pedestrian dust at 0.3 m height	1.5×10^{-6}–3×10^{-4}	
Particles settled in room	ZnS	Vigorous work, sweeping	1.9×10^{-4}	Fish et al., 1967
	MMD = 3.1 μm	Walking	3.9×10^{-5}	
	$\sigma_g = 1.9$	Light work	9.4×10^{-6}	
	CuO	Light sweeping	7.1×10^{-4}	
	MMD = 2.0 μm			
	$\sigma_g = 2.3$			
Civil defense trial	^{131}I	Bomb-recovery operation with brick/plaster dust		Stewart, 1967
		Enclosed space	4×10^{-5}–2×10^{-4}	
		Open area	2×10^{-6}	
Nevada Test Site	Plutonium	Extensive vehicular traffic	7×10^{-5}	Langham, 1971
Laboratory room	Plutonium oxide	No movement	2×10^{-8}	Jones and Pond, 1967
		14 steps/min	10^{-5}	
		36 steps/min	5×10^{-5}	
	Plutonium nitrate	No movement	2×10^{-8}	
		14 steps/min	10^{-6}	
		36 steps/min	5×10^{-6}	
Monte Bello Islands, Hurricane trails	Fallout	Road survey from back landrover		Stewart, 1967
		4th d	8×10^{-7}–3×10^{-5}	
		7th d	7×10^{-7}–4×10^{-6}	
		At tailboard, 7th d	1.6×10^{-5}–3.1×10^{-5}	
Australian desert, "Totem," 1953	Fallout gamma	Walking survey	3×10^{-7}	Stewart, 1967
		Vehicle survey		
		At tailboard	2×10^{-6}	

TABLE 12.9 (Continued)

Location	Source material	Resuspension stress	Resuspension factor range, m^{-1}	Reference
Contaminated field	Plutonium	Inside vehicle	2×10^{-5}	Calculated from Milham et al., 1976
		Downwind tractor	$5 \times 10^{-8} - 1.0 \times 10^{-6}$	
		In tractor cab	2.4×10^{-7}	
		Fertilizing	7.9×10^{-9}	
		Subsoiling	5×10^{-6}	
		Planting, light disking	$1.8 \times 10^{-8} - 7.9 \times 10^{-6}$	
		Mowing	1.3×10^{-5}	
Tractor cab in contaminated field	Plutonium	Tractor operations	$4 \times 10^{-9} - 2 \times 10^{-7}$	Milham et al., 1976
New York	Fallout plutonium	Average air concentration/surface concentration	$5 \times 10^{-6} - 2 \times 10^{-6}$	Calculated from Bennett, 1976
Palmares, Spain	Plutonium	Yearly average farming	$1.2 \times 10^{-10} - 3.8 \times 10^{-7}$	Calculated from Iranzo and Salvador, 1970
Contaminated sludge	Plutonium	Rototilling	5.6×10^{-8}	Calculated from Myers et al., 1976

TABLE 12.10 Air Concentration Dependency on Wind Speed

Location	Source material	Concentration increases with wind speed to power n: u^n	Concentration increases with wind speed to power n: u_*^n	Reference
Nevada Test Site, Baneberry	Gross gamma			Anspaugh et al., 1973
Nevada Test Site, GMX	Plutonium		2.2	Anspaugh et al., 1976
Nevada Test Site, Yucca Flat	Plutonium	Increases a factor of 10 from u <2 m/s to u = 5 to 7 m/s		Mork, 1970
Rocky Flats	Plutonium	2.1		Sehmel and Orgill, 1973
Rocky Flats	Plutonium	5.9		Sehmel and Lloyd, 1976
Hanford				
On-site	Plutonium	1.0–1.5		Sehmel, 1977b
Off-site	Plutonium			Sehmel, 1977a
	<5 m/s	1.1		
	>5 m/s	3.0–9.3		
Hanford	Tracer	1.0–4.8		Sehmel, 1977a
Eroding field	Soil particle diameter, μm			Sehmel and Richmond, 1978
	0.4–0.6		2.6–3.4	
	0.6–0.7		5.0	
	2.7–2.9		6.4	
Eroding agricultural field	Soil		6.38	Shinn et al., 1976; Anspaugh et al., 1975
Nevada Test Site, desert pavement			2.1	

TABLE 12.11 Resuspension Rates

Location	Source material	Resuspension rate, s^{-1}, determined from: Calculation using transport model and concentration at only one height	Integration of measured concentrations	Reference
Corn leaves	Pollen		10^{-6} to 10^{-4}	Calculated from Aylor, 1976
Nevada Test Site	Plutonium	2.7×10^{-12} to 4.8×10^{-10}		Anspaugh et al., 1975
Nevada Test Site, GMX	Plutonium	10^{-12} to 10^{-10}		Healy, 1974
Nevada Test Site	Plutonium	1×10^{-10} to 6×10^{-8}		Healy, 1974, calculated from Wilson, Thomas, and Stannard, 1960
Hanford Site	ZnS	1×10^{-8} to 3.5×10^{-6}		Healy, 1974, recalculation of Healy, 1955, and Healy and Fuquay, 1958
Eroding field from top 1 cm depth	Soil			Calculated from Skidmore and Woodruff, 1968
0.5 ton/(acre • month)		2×10^{-9}		
40 tons/(acre • month)		2×10^{-7}		
310 tons/(acre • month)		1×10^{-6}		

They were measured during selected wind speeds and increased with the 1.0 to 4.8 power of wind speed.

Average wind-induced tracer resuspension rates of both respirable and nonrespirable particles are shown in Fig. 12.9. Average resuspension rates for nonrespirable particles were nearly independent of time and were on the order of 10^{-11} fraction resuspended per second. Average resuspension rates for respirable particles ranged from about 10^{-11} to 10^{-7} fraction resuspended per second and did not decrease with time.

Resuspension rates cannot be predicted as a function of the diameters of the source particles or the physical and chemical properties of the particles. There are too few data even to predict differences between resuspension rates for the same pollutant for surfaces with different vegetation coverage.

12-5.2 Correlation for Wind-Induced Resuspension Rates

Resuspension rates measured in several other experiments (Sehmel, 1975a) are plotted in Fig. 12.10 as a function of aerodynamic surface roughness height. In this figure, resuspension rates range over 7 orders of magnitude, from 10^{-10} to 10^{-3} fraction resuspended per second. For an estimate of fractional removal per year, these rates need to be compared with the 3.2×10^7 seconds in a year. Figure 12.10 is a guideline for estimating resuspension rates for other aerodynamic roughness heights. However, this correlation with aerodynamic surface roughness should be used with extreme caution. For accuracy, resuspension rates should be determined as a function of physical parameters other than aerodynamic surface roughness alone. Until better correlations are developed, however, this correlation does give some justification for estimating resuspension rates.

12-5.3 Resuspension by Vehicular Traffic

Resuspension rates for vehicular traffic on an asphalt road are shown in Fig. 12.11 as a function of vehicle speed (Sehmel, 1973c). The resuspension rate was calculated by determining the fraction of the tracer resuspended each time the vehicle was driven along the road. The fraction of tracer resuspended each time the vehicle passed ranged from 10^{-5} to 10^{-2}. Resuspension rates did increase with vehicle speed. Also, when vehicles were driven on the lane containing the tracer, the resuspension rates were greater than when the vehicle was driven on the lane adjacent to the tracer lane. For vehicle speeds above 32 km/h (20 mph) on the tracer lane, resuspension rates for both car and truck passage were found to be comparable.

These rates were also found to depend on the time the tracer particles had been on the asphalt road. After the tracer had been on the road for 4 d, the particle resuspension rates decreased, as Fig. 12.12 shows. Even considering the influence of time, resuspension rates were still greater when the vehicle was driven through the tracer lane than when it was driven on the adjacent lane.

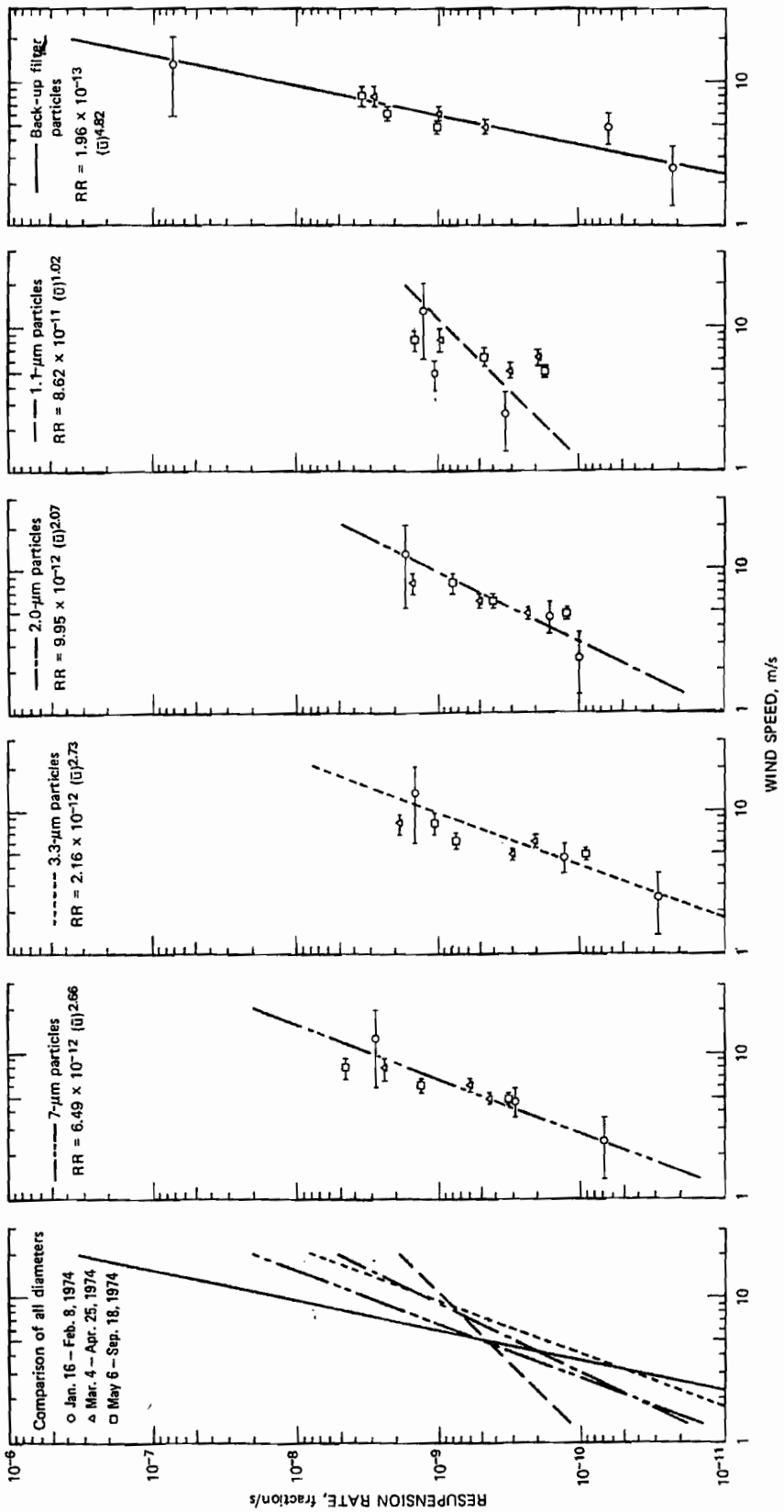

Fig. 12.8 Tracer resuspension rates as a function of particle diameter and wind speed increments.

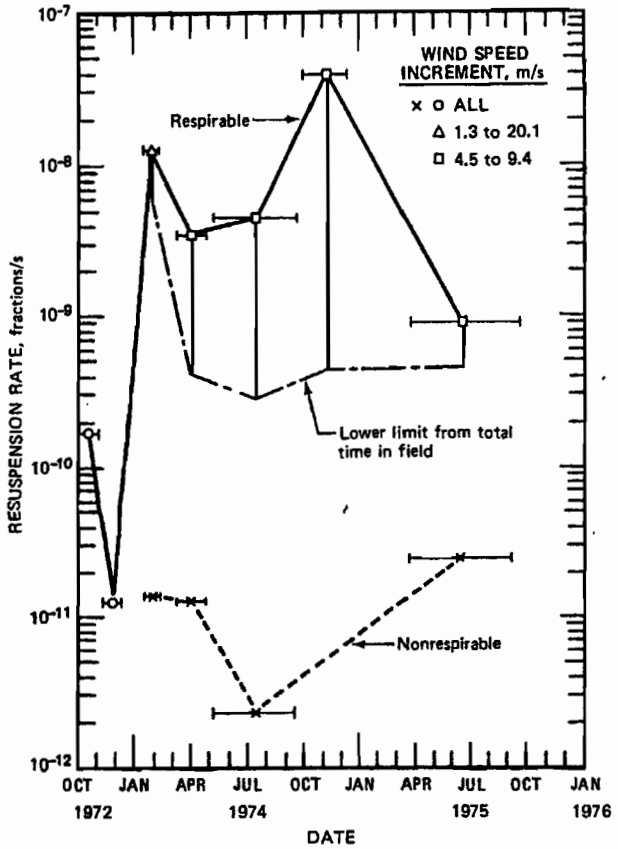

Fig. 12.9 "Average" wind caused tracer resuspension rates (lightly vegetated desert on the Hanford site).

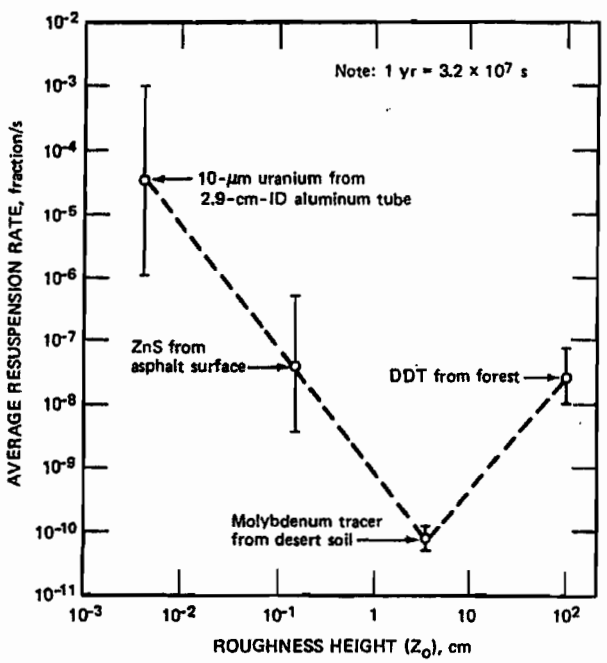

Fig. 12.10 Initial correlation of wind caused tracer resuspension rates.

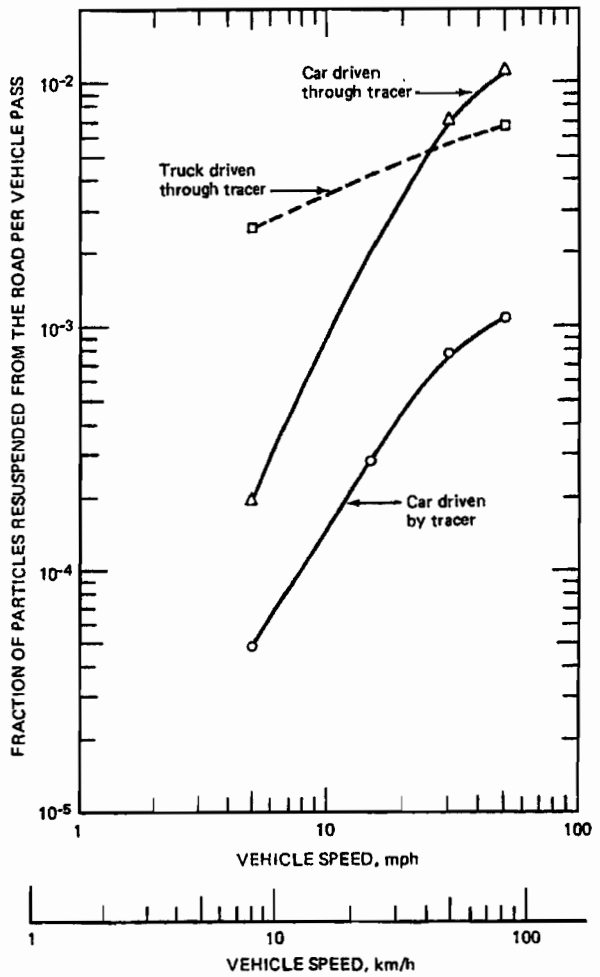

Fig. 12.11 Rates of tracer particle resuspension caused by vehicle passage over an asphalt road 4 d after particle deposition.

Sehmel (1976a) also determined that truck traffic in a cheatgrass area caused less resuspension than truck traffic on an asphalt road because the vegetation prevented part of the turbulence generated by the truck from reaching the ground and resuspending the tracer. Figure 12.13 compares the resuspension rates for both surfaces.

Although increased resuspension rates are expected at higher speeds because of turbulence, Sehmel found that the resuspension rates decreased for the cheatgrass road as speed increased from 8 to 48 km/h (5 to 30 mph). This decrease can be attributed to the sequence of truck speeds used in the experiment. The initial resuspension experiment was conducted at 8 km/h (5 mph). At this low speed the most readily resuspended tracer particles were removed from the cheatgrass. Only when the truck speed was increased from 48 to 64 km/h (30 to 40 mph), with the consequent increase in air turbulence, did resuspension rates increase.

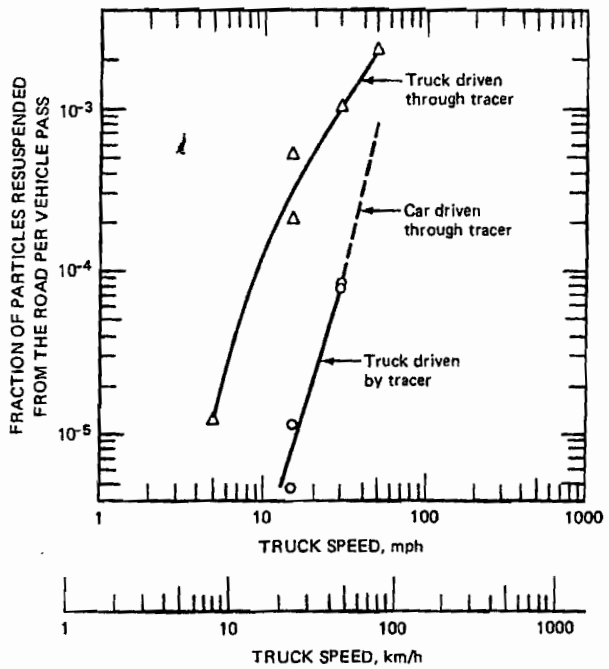

Fig. 12.12 Rates of tracer particle resuspension caused by vehicle passage over an asphalt road 4 d after particle deposition.

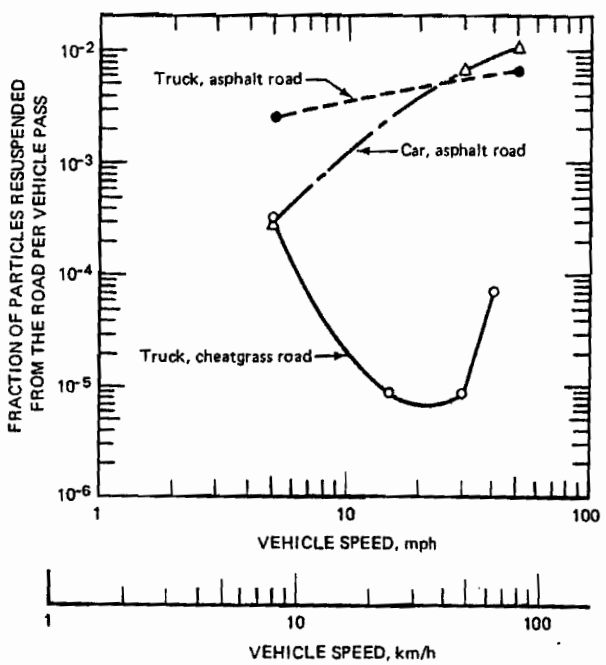

Fig. 12.13 Rates of tracer particle resuspension caused by vehicle passage over asphalt and cheatgrass roads.

12-5.4 Resuspension by Pedestrian Traffic

Resuspension caused by pedestrian traffic was determined as the fraction of tracer particles resuspended each time a person walked the length of a tracer lane. A man walking along a tracer lane on an asphalt road caused a fraction from 1×10^{-5} to 7×10^{-4} of the tracer to be resuspended with each pass.

12-6 CONCLUSIONS

Mass transfer across the air–surface interface is important for all toxic materials, regardless of their size. If the materials are respirable, predicting the concentrations that might potentially be inhaled is crucial. These concentrations can be calculated from atmospheric diffusion and transport models that include a boundary condition for mass transfer across the air–surface interface. The problem is that many of these models either have not been validated or have been validated only under limited conditions. Models have not been validated, for instance, for the case of significant air–surface mass transfer. Once these models are validated, deposition velocities and resuspension rates will be available. Until then, they may not be the best available method of predicting downwind concentrations.

Although many experiments have been conducted and theoretical models have been developed to predict the effects of particle and gas deposition since the literature was reviewed in *Meteorology and Atomic Energy—1968* (Slade, 1968), our ability to predict surface mass-transfer deposition rates from those field experiments has not improved significantly, with one exception. A model developed by Sehmel and Hodgson (1978) to predict deposition velocities is considered to so improve our capability to predict deposition velocities that it should be used until either more refined and definitive deposition experiments are completed or improved predictive models are developed from the existing data.

Accurate predictions of surface depletion of airborne pollutant plumes from anthropogenic sources require that the best available estimates for dry deposition velocities be used. However, the relative significance of dry deposition has only recently been appreciated in the literature. Earlier deposition experiments were focused on the wet removal of nuclear fallout debris from the stratosphere rather than on dry deposition near ground level. The fact that fallout is removed primarily by wet deposition has overshadowed a more important consideration: the key role of pollutant release height in determining the relative effectiveness of dry vs. wet removal processes. Since most energy sources release pollutant near ground level, studies of dry deposition may be more significant than studies of wet deposition in predicting the removal of pollutants from the atmosphere.

A limitation of early field experiments was that experimental variables were not adequately controlled, i.e., the particle size distribution was either not known or not reported. However, deposition velocities are a function of particle diameter. Consequently most field-determined mass-transfer data should be interpreted with qualification. The deposition velocities determined in these field experi-

ments ranged from 10^{-5} up to 20 cm/s, a range also predicted by Sehmel and Hodgson's empirical model.

The model predicts deposition velocities as a function of particle diameter, friction velocity, aerodynamic surface roughness, and particle density. These predictions emphasize that the distribution of pollutant particle size must also be known, but the model does not include any geometrical parameter. The model does include a minimum deposition velocity of 0.025 cm/s. For smaller particles and gases, deposition velocities increase because of Brownian diffusion. For larger particles, deposition velocities increase because of gravitational settling and eddy diffusion.

Resuspension, the other mass-transfer process discussed in this chapter, has been receiving increased attention in the last several years, as is evidenced in the 1974 conference proceedings (Engelmann and Sehmel, 1976) which considers both resuspension and dry deposition. Resuspension can be a continuing problem after toxic materials are deposited on environmental surfaces. After the material is on the ground, it will be recycled into the atmosphere to be inhaled by man. This chapter has demonstrated that resuspension physics are so poorly defined that much research is needed.

One problem is that resuspension coefficients have not been adequately defined. One resuspension coefficient relates airborne concentrations to local surface-contamination levels but does not describe either the vertical flux from resuspension or the total downwind flux. Any calculation using an "average" resuspension factor must be qualified as being uncertain within 2 to 3 orders of magnitude because resuspension factors, which cannot be predicted, have ranged 2 to 3 orders of magnitude even in a single field experiment. The second resuspension coefficient describes the resuspension rate, i.e., the fraction of material resuspended per unit time. If the surface contamination level is known, the vertical flux from resuspension is the product of resuspension rates and source concentrations, using this coefficient. Resuspension rates measured for both wind and mechanical stresses indicate that mechanical stresses can cause more material to be resuspended at one time than does wind, but the effect is short-lived because mechanical stresses usually last over less time and space.

Deposition and resuspension research results are equally applicable to pollutants from both nuclear and nonnuclear energy sources. Differences in these air–surface mass transfer processes cannot be distinguished as a function of chemical properties. Dry deposition can be predicted as a function of particle size, but resuspension cannot.

Experimental deposition and resuspension research are needed to define the transport and mass-transfer processes more adequately. In future studies of these processes, the experimental conditions must be controlled and defined, and the experimental techniques used and the theoretical interpretation of the results must be validated. Model and experimental validation are the crux and requirement for future research of air–surface mass-transfer processes.

12-7 APPLICATIONS

This chapter has summarized the literature on dry deposition of particles and gases and resuspension of particles. In addition, data describing dry deposition and resuspension have been tabulated. However, use of the summarized data must always be qualified since the data cannot be generalized. It is hoped that generalizations will be forthcoming, but until such generalizations are formed, the data must be used with caution. When applying these data, the user must be aware of their limitations, even when, as is often the case, available data are too limited to indicate guidance.

Possibly one of the most important limitations is that particle size has been inadequately reported in much of the literature. Nevertheless, there are different particle diameters that might be of greatest interest, depending on the user's viewpoint regarding application. For instance, pollution depositing on environmental surfaces, including biological and ecological surfaces, might indicate that one particle size was a larger problem area to the biota than another particle size. These particles are usually larger than respirable. In this summary, however, the respirable particle size range is emphasized.

12-7.1 Particle Size

Normally the diameter of respirable particles is less than about 3.5 μm, whereas the diameter of inhalable particles is less than 15 μm. If we specify that our prime interest is particles that are respirable and inhalable to 15 μm, then the next analysis step is to estimate or measure the particle size distribution. Although the particle size distribution is usually estimated from literature sources, here only direct experimental particle size measurements will be considered.

Ideally, particle collection is by isokinetic sampling, which describes the collection of airborne particulates while not disturbing the motion of the approaching air. If the air sampling velocity (vector) does not match the velocity (vector) of the approaching air, particle inertia will cause relative particle motion with respect to air motion. Hence particle collection will deviate from the motion of the free air. In determining the particle size, we need to be aware of possible particle-sampling biases introduced by non-isokinetic air sampling; otherwise, resulting predictions would also show a bias that is not properly qualified for particle size uncertainty.

As a hypothetical example of bias to illustrate the point, consider the measurement of airborne plutonium arising from particle resuspension. The airborne plutonium consists of two different monodispersed particle diameters of either 1 μm (a respirable particle) or 100 μm in diameter (a nonrespirable particle). For this hypothetical size distribution, predictions are to determine if airborne concentrations are within (that is, less than) a maximum permissible airborne concentration as given by health standards (ICRP, 1959; ERDA, 1977). The true air concentration of resus-

pended respirable plutonium particles (1 μm) is assumed to be at the limit set by the maximum permissible airborne concentration guide; i.e., this maximum permissible concentration, $MPC_{168\,h}$, is 6×10^{-14} μCi/cm^3 (ERDA, 1977).

In many applications for plutonium, the entire size distribution of airborne particles is characterized by a single sample containing only respirable particles. For such a case the total airborne concentration could be increased by air sampling for both 1-μm-diameter particles and 100-μm-diameter particles. Thus the predicted airborne hazard based on the total sample would increase because of the increased plutonium collection. However, if the absolute concentration of 1-μm particles remained at the maximum permissible airborne concentration, the real airborne hazard would not be increased by simply including both respirable and nonrespirable particles in the sample. Similarly, in many applications, the entire size distribution of airborne particles is characterized by a single particle diameter, for instance, the activity median aerodynamic diameter (AMAD). For such a case, the AMAD could be increased by air sampling for both 1-μm diameter particles and 100-μm-diameter particles. Thus the predicted airborne hazard based on the AMAD would decrease because of the increased average particle diameter. However, if the absolute concentration of 1-μm particles remained at the maximum permissible airborne concentration, the real airborne hazard would not be decreased by simply including both respirable and nonrespirable particles in the sample. Therefore anyone who uses the data must be aware of, at least, some limitations and problems in particle sampling and data interpretation. Some of these problems will be considered below.

12-7.2 Resuspension Source Characterization

In calculating resuspension, we are frequently faced with the problem of how to characterize the source material on the ground. In other words should the toxic material be characterized as a function of particle size, or should it be characterized simply as the gross amount of pollutant on the ground? Both approaches have serious problems when we consider existing knowledge. For instance, consider some problems in determining the toxic particle size distribution on the ground (assuming that the toxic material is on the ground rather than on vegetation). Even if pollutant particle size distributions were known when the pollutant was deposited, we must consider whether the resuspension-controlling particle size is the toxic material size or the agglomerate size of toxic material particles attached to host soil particles.

Although particle size must have an effect on resuspension, neither the theoretical nor experimental data base for resuspension has yet been developed with enough precision to allow us to predict the particle size dependency with confidence. For instance, we can hypothesize whether the toxic material is in the respirable size range or whether the total material should be used to characterize the resuspension source strength for the surface soil. From a theoretical standpoint, we would like to predict resuspension as a function of the particle size distribution on the ground surface. Even on this theoretical basis, practical problems exist in quantifying the pollutant size distribution on the ground. For example, there are at least two approaches: (1) analyze a surface soil sample in the laboratory and (2) use a portable wind tunnel to suspend surface material for subsequent sampling at the wind-tunnel outlet. Neither approach is strictly comparable to resuspension by either wind or local mechanical stresses since (1) a single surface soil sample is representative only if the entire available surface is uniform and (2) there may not be a quantitative one-to-one correspondence for particles on the ground and in the air.

Since considerable effort is currently being expended in collecting surface soil samples for subsequent laboratory analysis of the particle size distribution, let us consider some theoretical problems with this approach. The problems considered are associated with modifying the parent size distribution in the laboratory. Dry sieving through screens is one technique for determining particle size distributions. Release of smaller particles from host particles by impact on the screens might be similar to release of these particles from host particles during impact from dropping. For instance, particles of 0.2- to 0.8-μm diameters are released (Sehmel, 1978a) when a 1-mm-diameter particle is dropped 51 cm to impact on a solid surface. Similar particle releases by wet sieving are expected to alter the apparent particle size of distribution. Particles have been shown (Rosinski et al., 1976) to become detached from host particles when the host particle is dropped into liquid. Thus, when determining particle size distributions, we should be aware of the technique used for particle size analysis; it could significantly alter the parent size distribution. However, considering existing technology, we may have little choice of the techniques used. Although optical and electron microscopy are also available, these techniques are very expensive to use on a routine basis, and the data are always qualified since only a very small sample is usually viewed.

Another problem is that source-sampling strategies require the assumption of a uniform resuspension source or the experimental determination of the areal variation in source strength. For instance, should a surface sample be selected under vegetation or between vegetation, between rocks or on top of rocks, or are there more representative sampling sites that can be selected based on either known or expected deposition patterns?

An economic problem as well as a scientific problem arises when we consider nonhomogeneous resuspension sources. The inference is that costs usually indicate that only relatively small surface samples can be analyzed. However, I feel that costs for particle size determination of a small 1-cm^2 or 100-cm^2 surface sample would be more profitably expended by additional gross surface samples to

define more accurately the areal distribution of the source strength.

Another practical problem in defining source strength is soil sampling depth. For instance, should the sampling depth be 1 mm, 1 cm, 5 cm, or some other depth? Various depths as well as samplings have been used as a function of depth. If the total source strength is desired, the sampling depth is not too important (except for the greater cost involved in analyzing for toxic material in a greater soil volume) as long as the greatest portion of toxic material is within the sampling depth. However, if we are interested in determining the source strength available for immediate resuspension, only the surface material should be sampled.

Surface source strength changes with time because toxic material migrates into the soil. After some time, the logarithm of concentration might be expected to decrease linearly with depth. However, if the toxic material is leached by precipitation or if the source has been covered by clean soils, a maximum soil concentration could occur at some distance below the surface. In this case, concentrations would not exhibit a simple exponential decrease with depth, and the surface concentration could not be determined by extrapolating concentrations determined at greater depths. Although various problems exist in characterizing resuspension surface source strengths, the practical solution appears to be a sampling depth of about 1 mm to 1 cm. The 1-mm sampling depth might be obtained by a vacuuming technique, and the 1-cm depth might be obtained by a scooping technique.

12-7.3 Estimation of Deposition Velocity

In estimating deposition velocities, we must be aware of the basic assumptions required for applying air–surface mass-transfer rates described by dry deposition velocities. Often the estimator has assumed that the deposition velocity is constant at 1 cm/s for all situations considered. This simplification is a mathematical convenience that often does not occur in the real world.

Dry deposition velocities are a function of the many variables discussed in this chapter, but here dry deposition velocities are emphasized to be a function of particle diameter, even for gases. The assumption is that gases become attached to airborne condensation nuclei particles, and, as a result, the gas diffusion coefficient is altered. The pure gas has a higher Brownian diffusion coefficient than gas sorbed on particles since sorbed gas has a Brownian diffusion coefficient corresponding to the host airborne particle. The Brownian diffusion coefficient of a particle is less than that for a gas and decreases as the particle size increases. Therefore, for particle diameters less than 0.1 μm, the final deposition process within the 1 mm adjacent to a deposition surface is often controlled by Brownian diffusion.

Next, consider the single deposition velocity describing an airborne particle size distribution. An effective deposition velocity, v_d, is needed to account for the size distribution. To calculate an effective deposition velocity, we must first know the deposition velocity, $k_{1\ m}$, for each particle size within the airborne particle size distribution. Thus the effective deposition velocity at any one location is the summation over particle diameters, i, of

$$v_d = \frac{\Sigma(K_{1\ m})_i\, \chi_i}{\chi} \tag{12.11}$$

In addition, the effective deposition velocity is a function of downwind distance since each particle size is depleted from the airborne plume with different mass-transfer rates. That is, the particle plume will show relatively more depletion at the air–surface interface for all particle diameters outside the range of 0.1 to 1 μm than for particles within that range. To determine either the average airborne concentration or the effective deposition velocity at some downwind location, we should calculate airborne concentrations for each particle size. Subsequently, airborne concentrations are summed for each particle size, and the total average concentration is determined.

In general, however, these summations have been neglected by most estimators. This neglect may not be justifiable in all applications unless the resulting concentration predictions are conservative for the situation being considered. Even if the estimator considers that the conservative prediction of airborne concentrations is calculated by neglecting plume depletion at breathing height, he makes the assumption that atmospheric transport models have been validated with data for most situations. However, there has been limited transport model validation even to 3 to 10 km (Crawford et al., 1977, 1978, and American Meteorological Society 1977 Committee on Atmospheric Turbulence and Diffusion, 1978). In addition, a basic requirement in the assessment of potentially dangerous conditions is that realistic estimates of airborne concentrations can be calculated, but such an assessment is realistic only when plume depletion by dry deposition is considered.

In retrospect, then, the point is that we must be aware of the preceding assumptions and limitations that go into the computation and use of deposition velocity. Furthermore, other variables that can contribute to changing the deposition velocity include atmospheric stability, wind speed and direction, aerodynamic surface roughness, friction velocity, modification of these parameters by local terrain, and diurnal and seasonal variations, in addition to the other variables listed in Table 12.1, including gravitational settling, particle size and shape, and gas solubility in water. These areas will not be discussed further, but they must be considered for each individual situation, even if their effects on resuspension and deposition cannot always be predicted.

12-7.4 Illustrations

Several applications of the data summarized in this chapter are presented here as potential guidelines. Examples

are given for calculating deposition velocities, resuspension factors, and resuspension rates. Theoretical atmospheric transport model predictions of downwind airborne concentrations, based on deposition velocities and resuspension rates, could also be used to estimate airborne concentrations. For details on atmospheric transport, see Chaps. 6, 13, and 14.

12-7.4.1 *Deposition.* First, let us consider dry deposition. Assume that we are interested in predicting the deposition of a 1-μm-diameter monodispersed particle, having a density of 1 g/cm^3, over sagebrush when the particle release height is within 1 m of the ground. Instead of estimating the deposition velocities to calculate the plume depletion, in this case we can go directly to the first and third entries of Table 12.3 to estimate the plume depletion. Use of the 0.7-μm data for a 1-μm particle diameter is based on deposition velocities (see Figs. 12.3 to 12.7), which are nearly independent of particle diameters between 0.1 and 1 μm. Thus Table 12.3 predicts 22 to 32% plume depletion within 200 m, 10 to 54% plume depletion within 400 m, and 65% plume depletion within 91 m.

As an illustration of estimating a dry deposition velocity, assume the same conditions except that the particle diameter is now 5 μm. If we are fortunate enough to find similar experimental conditions in Table 12.4, the deposition velocity could be predicted. However, a completely similar experiment is not listed in Table 12.4, except possibly for 5-μm zinc sulfide at deposition velocities from 1.5 to 5.4 cm/s (Nickola and Clark, 1976).

For illustration purposes the deposition velocity will be selected from Figs. 12.3 to 12.7. To use these figures, we need both the aerodynamic surface roughness, z_0, and the friction velocity, u_*. Obviously, if experimental surface-roughness data were available for the situation being considered, that experimental surface roughness should be used. The friction velocity is estimated from Table 12.6. Although the listed surfaces do not include sagebrush, a surface roughness between 5 and 10 cm might be estimated from the long-grass data. A surface roughness of 5 cm and a wind speed of 5 m/s at 2 m are assumed. In this case, Table 12.6 suggests that the friction velocity is of the order of 0.6 m/s. The 0.6 m/s or 60 cm/s is used to determine the deposition velocities from Figs. 12.3 to 12.7. However, a friction velocity of 60 cm/s is not shown. A deposition velocity for 60 cm/s could be determined by interpolation (friction velocities between 50 and 100 cm/s), or we might assume that friction velocities of 50 and 60 m/s are comparable. In the latter case the deposition velocity for a friction velocity of 50 cm/s is used.

Looking at Fig. 12.5 for a friction velocity of 50 cm/s and a 5-μm particle diameter, we select a deposition velocity for a unit particle density and an aerodynamic surface roughness of 5 cm. For these conditions, a deposition velocity of 1 cm/s is predicted. For a smaller diameter of 0.3 μm, the deposition velocity is estimated to be 0.04 cm/s. Thus the deposition velocity for a particle diameter of 5 and 0.3 μm differs by a factor of 25.

From the preceding examples, we can see some difficulties that arise in calculating and predicting deposition velocities and, therefore, the importance of always providing the user with qualifying information on the assumptions used in the prediction calculations.

12-7.4.2 *Resuspension: Vehicular.* Now let us consider particle resuspension by vehicular traffic. Assume that an equal number of particles from 1 to 100 μm in diameter are on an asphalt road. Figures 12.11 to 12.13 indicate that no data are available to permit us to estimate the effects of different particle sizes on particle resuspension. Thus, in calculations, resuspension rates are assumed to be independent of particle diameter.

Then assume that resuspension occurs on the same day particles were deposited and that sedans are traveling at 25 m/s (55 mph). From the limited data in Fig. 12.11, which shows resuspension rates as a function of vehicular speed, the fraction resuspended from the road per vehicle pass is approximately 10^{-2}. Thus the fraction of material remaining on the road after one vehicle pass is 0.989, and the fraction remaining after n vehicle passes is $(0.989)^n$. Only 50% of the source would remain on the road after 53 sedans had driven through the tracer, and only 1% would remain after 352 sedans had driven through the tracer. However, at urban speeds of 56 km/h (35 mph), the fraction of particles resuspended from the road per sedan pass is 8.2×10^{-3}. Thus 84 sedan passes are required for 50% source removal. After 559 sedans had passed, only 1% of the source would remain.

12-7.4.3 *Resuspension: Wind.* Airborne concentrations from resuspension can be calculated from either resuspension factors (Tables 12.7 and 12.9) or from resuspension rates (Figs. 12.8 to 12.10 and Table 12.11). Possible applications of both resuspension factors and resuspension rates will be discussed.

In practice you may be interested in several types of resuspension predictions, including predictions of airborne concentrations at breathing height for people within contaminated areas, predictions of downwind airborne concentrations from resuspension, and predictions of changes in surface source contamination levels. Calculations using resuspension factors will be considered first. Resuspension factors, m^{-1}, are defined as the airborne concentration per cubic volume of air, m^{-3}, divided by the surface contamination per unit area, m^{-2}, below the airborne concentration measurement site. Resuspension factors are most useful for predicting airborne concentrations above contaminated surfaces; however, resuspension factors are not rates and are not useful in predicting changes with time in surface contamination levels.

The prediction of an average resuspension factor must always be qualified by uncertainty, since no correlation for predicting resuspension factors exists. As shown in

Table 12.7, the range of the wind-caused resuspension factor is from 9×10^{-11} to 3×10^{-4} m^{-1}—a range of 6 to 7 orders of magnitude. Even within one experimental location, the range can be over 3 orders of magnitude. If you are faced with having to estimate a resuspension factor, try to find a similar situation in Table 12.7, but use the number with caution.

12-7.4.4 *Resuspension: Mechanical.* Resuspension factors can be estimated for mechanical stresses from Table 12.9. However, there is no general correlation for predicting resuspension factors. These resuspension factors range over 8 orders of magnitude, from 1.2×10^{-10} up to 4×10^{-2} m^{-1}. Even within a single experiment, resuspension factors can range over 2 orders of magnitude. Thus uncertainties in predicting resuspension factors are very large. Resuspension factors cannot be predicted as a function of the source characteristics, particle size, particle density, or amount of mechanical stress producing resuspension.

12-7.4.5 *Wind-Induced Resuspension Rates.* The fraction, G/G_0, of a resuspension source remaining after time t is

$$G/G_0 = e^{-St} \tag{12.12}$$

To obtain a feel for the source strength as a function of time and resuspension rates, defined as the fraction of surface contaminant removed per second, compare the rate to the 3.2×10^7 s equal to 1 yr. If a resuspension rate were constant at 1×10^{-8} s^{-1}, 27% of the resuspension source would be depleted in a year. At a constant resuspension rate of 1×10^{-11} s^{-1}, only 0.03% of the resuspension source would be depleted in a year. For resuspension rates in the order of 10^{-11} to the 10^{-8} s^{-1}, material will continue to resuspend for many years. Similarly, if it is assumed that weathering does not occur, the resuspension source strength will also remain essentially constant for many years.

Resuspension rates caused by wind stresses can be estimated from Figs. 12.8 to 12.10 and from Table 12.11. Resuspension-rate variability will be considered first. For instance, in Table 12.11 resuspension rates for general surface sources range from 10^{-12} to 10^{-6} s^{-1}. The resuspension rates are of interest when they are compared to the resuspension rates calculated from agricultural erosion considerations. For instance, soil erosion rates of 0.5, 40, and 300 tons/(acre · month) were selected. These erosion rates were converted to average resuspension rates by assuming a 1-cm source depth for eroding soil. On the basis of this assumption, resuspension rates increased from 2×10^{-9}, 2×10^{-7}, and 1×10^{-6} s^{-1} for the three soil erosion rates, respectively. These resuspension rates are within the same orders of magnitude as those measured for pollutant resuspension. It is not known whether this similarity indicates a valid approach for calculating average resuspension rates for pollutants. The validity is questioned since erosion rates are determined for total soil movement rather than for the respirable particle size range for resuspension. Nevertheless, if you need to calculate resuspension rates for field conditions, you might justifiably calculate average resuspension rates from agricultural erosion equations until resuspension rates are experimentally determined or generalizations are made.

Although resuspension rates calculated from agricultural erosion data are in the range of resuspension-rate measurements shown in Figs. 12.8 to 12.10, a recommended procedure is required. If any of the experimental conditions are similar to your conditions, the best approach is to use resuspension rates measured for the similar conditions. This similarity will usually be the exception. For other conditions the recommendation is that resuspension rates be selected from Fig. 12.9, which gives the temporal variability of wind-caused tracer resuspension rates. A range of resuspension rates could be selected from the data shown in Fig. 12.10 for use in sensitivity analysis. Admittedly, this correlation is based only on the aerodynamic surface roughness height. There are many other variables discussed in this chapter that also should influence resuspension rates, but their effects are unknown.

Our ability to predict resuspension rates is limited by great uncertainty in the selected values, and, unfortunately, too few data exist for developing a more refined generalized resuspension-rate correlation. Much research is needed to develop a better generalized resuspension-rate correlation.

In any theoretical modeling approach using either resuspension rates or deposition velocities, you must be concerned with informing the reader about the model validity and the uncertainties in model predictions. Too many decisions are being made on the basis of numerical values predicted from models without considering the uncertainties in the numerical values. Even though we are using theoretical models at the forefront of science, we must be scientifically honest in our predictions. Uncertainties in those predictions must be communicated to the scientific community, to the legislative bodies, to those satisfying legal regulations, and especially to the general public. In the environmental pollution area, we must have the courage to continue to use and apply the most valid models, and we must also have the courage to conclude that existing modeling approaches may not be the best for predicting airborne concentrations. We must also have the courage to develop and to use, although not as theoretically satisfying, pragmatic approaches that will yield required answers.

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LIST OF SYMBOLS

Symbols used in Chap. 12 are listed here. The dimensions mass, length, and time are abbreviated as M, L, and T, respectively. Equation numbers indicate where the symbol first appears or where additional clarification can be found.

- C Airborne concentration of monodisperse particles (L^{-3}), Eq. 12.2
- d Zero-displacement plane (L), Eq. 12.9
- D Particle diameter (L), Eq. 12.7
- F Deposition flux (units $L^{-2}\ T^{-1}$), Eq. 12.1
- G Pollutant concentration on ground per unit area but to an unspecified depth (units L^{-2}), Eq. 12.3
- k von Kárman's constant (dimensionless), Eq. 12.8
- $K_{1\ m}$ Deposition velocity for a single particle diameter with the airborne concentration measured at an elevation of 1 m (LT^{-1}), Eq. 12.2
- N Number of particles (L^{-3}), Eq. 12.7
- Q Soil drift perpendicular to the wind direction ($ML^{-1}\ T^{-1}$), Eq. 12.5
- RF Resuspension factor (L^{-1}), Eq. 12.3
- S Suspension or resuspension rate (fraction resuspended/T), Eq. 12.4
- S_{air} Suspension rate for particles moving in true airborne suspension air (fraction resuspended/T), Eq. 12.4
- S_{salt} Suspension rate for particles moving in saltation (fraction salt resuspended/T), Eq. 12.4
- S_M Suspension rate caused by mechanical stresses (fraction resuspended/T), Eq. 12.4
- S_{sc} Suspension rate for particles moving in surface creep (fraction resuspended/T), Eq. 12.4
- S_W Suspension rate caused by wind stresses (fraction resuspended/T), Eq. 12.4
- t Time (T), Eq. 12.12
- u Air velocity (LT^{-1}), Eq. 12.5
- u_T Threshold velocity for soil transport (LT^{-1}), Eq. 12.6
- u_* Friction velocity (LT^{-1}), Eq. 12.8
- V Particle volume (L^3), Eq. 12.7
- v_d Deposition velocity for a polydisperse aerosol determined in the field (LT^{-1}), Eq. 12.1
- v_t Monodisperse particle gravity settling velocity (LT^{-1}), Eq. 12.10
- z Height above ground (L), Eq. 12.8
- z_o Aerodynamic surface roughness (L), Eq. 12.8
- χ Airborne concentration of polydisperse particles (units L^{-3}), Eq. 12.1
- ρ Particle density (ML^{-3}), Fig. 12.3

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Chapter 12 covers research prior to May 1979.

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Table 5.8—MAXIMUM GROUND CONCENTRATION OF SO_2 DURING FUMIGATION AT TVA PLANTS (30-MIN AVERAGES)

	Plant A	Plant B	Plant C
F, ft^4/sec^3	23,000	31,000	67,000
h_s, ft	250	300	500
Q, tons/day	84	135	334
N (number of stacks)	8	4	2
Period of data	3/56 to 10/56	3/55 to 4/58	12/58 to 1/61
Number of fumigations	1	9	12
$\chi_{max.}$, ppm	0.4	0.6	0.6
Calc. h, ft	1350	1500	1900
b	0.05	0.06	0.05

5-3 DEPOSITION OF PARTICLES AND GASES (Isaac Van der Hoven)

List of Symbols

Symbols used frequently in Sec. 5-3 on the deposition of particles and gases are listed here. (The dimensions mass, length, time, and temperature are abbreviated as M, L, T, and D, respectively. The equation number indicates the first appearance of the symbol.)

C_D	Drag coefficient (dimensionless), Eq. 5.35
C_y, C_z	Sutton's virtual diffusion coefficients ($L^{n/2}$), Eq. 5.38
g	Gravitational acceleration (LT^{-2}), Eq. 5.35
h	Height of source above ground (L), Eq. 5.38
n	Sutton's parameter associated with stability (dimensionless), Eq. 5.38
Q', Q'_0	Initial source strength (MT^{-1}), Eq. 5.38
Q'_x	Depleted source strength at a distance, x, from the source (MT^{-1}), Eq. 5.42
r	Particle radius (L), Eq. 5.35
$\bar{u}$	Average value of the wind component in the direction of the mean horizontal vector wind (LT^{-1}), Eq. 5.38
v_d	Deposition velocity (LT^{-1}), Eq. 5.41
v_g	Fall velocity (LT^{-1}), Eq. 5.35
λ	Mean free path of air molecules (L), Eq. 5.37
μ	Atmospheric dynamic viscosity ($ML^{-1}T^{-1}$), Eq. 5.36
ρ	Particle density (ML^{-3}), Eq. 5.35
ρ_a	Atmospheric density (ML^{-3}), Eq. 5.35
σ_y, σ_z	Standard deviation of the distribution of material in a plume in the y and z directions (L), Eq. 5.44
$\bar{\chi}$	Average concentration (ML^{-3}), Eq. 5.38
ω	Amount of aerosol removed per unit time per unit area ($ML^{-2}T^{-1}$), Eq. 5.39

5-3.1 Gravitational Settling

The earth's gravitational field plays an important role in the deposition of particulate matter on the earth's surface. The rate of descent of the particle depends upon a balance between the aerodynamic drag force and the gravitational force exerted by the earth. For a smooth spherical particle, neglecting the effect of slip flow, this balance may be expressed as

$$\rho_a \, v_g^2 \, C_D = \frac{8}{3} \, r \, g \, \rho \qquad (5.35)$$

where the notation is as given in the list of symbols. Equation 5.35 cannot be solved directly for the fall velocity because the drag coefficient is an empirical function of the Reynolds number, Re, and therefore also of velocity. McDonald (1960) has conveniently plotted this empirical relation for $Re \geq 1.0$ from which values of fall velocity vs. particle size can be computed. For the Reynolds number range between 10^{-4} and 10, the relation $C_D = 24/Re$ may be used, and, since $Re = 2\rho_a v_g r/\mu$, Eq. 5.35 reduces to the familiar Stokes equation

$$v_g = \frac{2 \, r^2 \, g \, \rho}{9\mu} \qquad (5.36)$$

The effect of the slip flow upon the fall velocity is a function of the ratio of the mean free path of the air molecules to the particle size. It can be expressed by multiplying the fall velocity by a slip correction factor (Davis, 1945)

$$1 + \frac{\lambda}{r}\left[1.26 + 0.4 \exp\left(-\frac{1.1r}{\lambda}\right)\right] \qquad (5.37)$$

where λ is primarily a function of altitude.

The effect of shape upon fall velocities is, on the average, to reduce the velocity by about ⅔ from that of a smooth sphere. Smooth ellipsoidal particles theoretically will vary in fall velocities by factors ranging from 0.5 to 1.04.

At fall velocities less than about 1 cm/sec, the effect of sedimentation is negligible, and vertical movement of the particle is largely controlled by the larger vertical turbulent and mean air motions. Figure 5.4 (after Hage, 1964) shows the fall velocity of smooth spheres with a density of 5 g/cm³ as a function of the altitude and particle diameter, with inertia terms and slip flow corrections taken into account where significant. It can be seen that the predominant

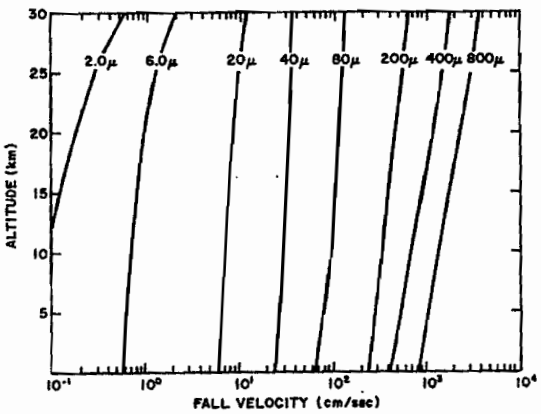

Fig. 5.4—Fall velocity of smooth spheres with a density of 5 g/cm³ as a function of altitude and particle diameter (microns). (From Hage, 1964.)

factor affecting fall velocity is the particle size. Similar fall-velocity computations for a particle with a density of 2.5 g/cm³ are given by McDonald (1960a).

In the range where the sedimentation rate is significant, the vertical transport of an initially airborne particle (fall velocity greater than about 1 cm/sec) depends upon horizontal as well as vertical transport and diffusion. For fall velocities ranging from about 1 to 100 cm/sec, the diffusion of a cloud of particles under homogeneous horizontal transport (no wind shear with height) can be described by assuming that the particles are diffused according to a statistical diffusion model, such as that of Sutton (1953), and at the same time that they will settle with appropriate fall velocities. For the case of an elevated plume, the effect is essentially that of the downward tilt of the plume center line, which can be expressed by replacing the constant height of the plume center line in the Sutton equation by a variable expression such that

$$\bar{\chi}(x,y,0) = \frac{2Q'}{\pi C_y C_z \bar{u} x^{2-n}} \exp\left\{-x^{n-2}\left[\frac{y^2}{C_y^2} + \frac{(h - xv_g/\bar{u})^2}{C_z^2}\right]\right\} \quad (5.38)$$

With the assumption that the particles are removed (deposited) when they reach the ground–air interface, the deposition pattern can be described by the expression

$$\omega = v_g \bar{\chi}(x,y,0) \quad (5.39)$$

where ω is the amount removed per unit time per unit area and $\bar{\chi}$ is the volumetric concentration pattern of the air at the surface.

Van der Hoven (1963) used this tilted plume model to describe the observed deposition pattern of radioactive effluents and included a cloud depletion factor (Csanady, 1955) of

$$1 - \frac{1}{(1-n/2)(h_0\bar{u}/xv_g - 1) + 2} \quad (5.40)$$

where n is one of Sutton's diffusion parameters. In practice the tilted plume model is only applicable in a well-mixed atmospheric layer, such as is typical of daytime adiabatic conditions within the lowest thousand meters.

The effect of horizontal wind-direction shear in the vertical becomes important as a diffusion mechanism if there is an initial distribution of particle sizes with height. With an initial cloud dimension of about 1000 m and particle fall velocities greater than 1 m/sec, the effect of turbulent diffusion on the ground deposition pattern can be neglected. The problem then becomes that of calculating particle trajectories using the appropriate fall velocity of each particle and the resultant wind vector of the atmospheric layer through which the particle falls. This technique as described by Kellogg, Rapp, and Greenfield (1957) has been applied primarily to the particle cloud resulting from surface nuclear-device detonations to calculate the fallout pattern for the first few hours after detonation.

5-3.2 Dry Deposition

5-3.2.1 Deposition Velocity. The observed fact that the deposition rate of small particles onto the ground can be greater than can be explained by the appropriate gravitational fall velocity has focused attention on nongravitational and nonprecipitation mechanisms, such as surface impaction, electrostatic attraction, adsorption, and chemical interaction. In analyzing the deposition of spores, Gregory (1945) concluded that the deposition rate was proportional to the immediate ground-level air concentration. Chamberlain (1953) defined the ratio of the deposition rate to the immediate ground-level air concentration as the deposition velocity, which, analogous to Eq. 5.39, can be stated as

$$\omega = v_d \bar{\chi}\,(x,y,0) \tag{5.41}$$

The interesting feature of such a formulation is that by using it as an experimental tool to compute v_d through the field or laboratory measurement of ω and $\bar{\chi}$, we can apply it to gases and vapors as well as to small particles. It in no way explains the physics of the deposition mechanism, but nevertheless it is a convenient way to express the whole complex and little-understood dry-deposition phenomenon.

5-3.2.2 Cloud Depletion. To account for the depletion of an airborne cloud because of dry deposition, Chamberlain (1953) modified Sutton's equation so that the original source term, Q'_0, was replaced by an effective depleted-source term, Q'_x. Thus, for a continuous source at ground level, the depletion factor was expressed by Chamberlain as

$$\frac{Q'_x}{Q'_0} = \exp\left(-\frac{4v_d\,x^{n/2}}{n\bar{u}\pi^{1/2}\,C_z}\right) \tag{5.42}$$

Using Eq. 5.41 and the modified Sutton equation, we can express the deposition rate per unit time per unit area for a source at ground level as

$$\omega = \frac{2Q'_0\,v_d}{\pi\bar{u}\,C_yC_z x^{2-n}}\exp\left(-\frac{4v_d\,x^{n/2}}{n\bar{u}\pi^{1/2}\,C_z}\right) \times \exp\left(-\frac{y^2}{C_y^2\,x^{2-n}}\right) \tag{5.43}$$

Chamberlain further expressed the depletion factor for the case of an elevated source. Culkowski (1958) has presented graphical solutions to these equations.

The generalized Gaussian diffusion formula (in the notation used in Chap. 3) can also be modified for cloud depletion. The depletion correction for a continuous elevated source can be derived as follows:

$$\omega(x,y) = v_d\,\bar{\chi}(x,y,0) = \frac{v_dQ'_x}{\pi\sigma_y\sigma_z\bar{u}}\exp\left[-\left(\frac{y^2}{2\sigma_y^2}+\frac{h^2}{2\sigma_z^2}\right)\right] \tag{5.44}$$

where $\omega(x,y)$ is the surface deposition at (x,y) and Q'_x is the residual source at x meters downwind. The depletion of the source per unit distance is given by

$$\frac{\partial Q'_x}{\partial x} = -\int_{-\infty}^{\infty}\omega(x,y)\,dy = -\left(\frac{2}{\pi}\right)^{1/2}\frac{v_dQ'_x}{\bar{u}\sigma_z}\exp-\left(\frac{h^2}{2\sigma_z^2}\right) \tag{5.45}$$

which can be rearranged as

$$\int_0^x\frac{dQ'_x}{Q'_x} = -\left(\frac{2}{\pi}\right)^{1/2}\frac{v_d}{\bar{u}}\int_0^x\frac{dx}{\sigma_z\exp(h^2/2\sigma_z^2)} \tag{5.46}$$

If $Q'_x = Q'_0$ at $x = 0$, then

$$\ln\frac{Q'_x}{Q'_0} = -\left(\frac{2}{\pi}\right)^{1/2}\frac{v_d}{\bar{u}}\int_0^x\frac{dx}{\sigma_z\exp(h^2/2\sigma_z^2)} \tag{5.47}$$

and therefore

$$\frac{Q'_x}{Q'_0} = \left[\exp\int_0^x\frac{dx}{\sigma_z\exp(h^2/2\sigma_z^2)}\right]^{-(2/\pi)^{1/2}v_d/\bar{u}} \tag{5.48}$$

Since σ_z is not generally available as an analytical function of x in the generalized Gaussian form, the integral expression in Eq. 5.48 was evaluated numerically using the experimentally derived values of $\sigma_z(x)$ given by Hilsmeier and Gifford (1962). Figure 5.5 shows the depletion fraction, (Q'_x/Q'_0), as a function of distance from the source, diffusion category (in terms of Pasquill types or the corresponding values of σ_θ as given in Chap. 4, Sec. 4-4.4), height of release, a deposition velocity of 1 cm/sec, and a mean wind speed of 1 m/sec. To obtain depletion fractions for other deposition velocities and wind speeds, we may use the expression

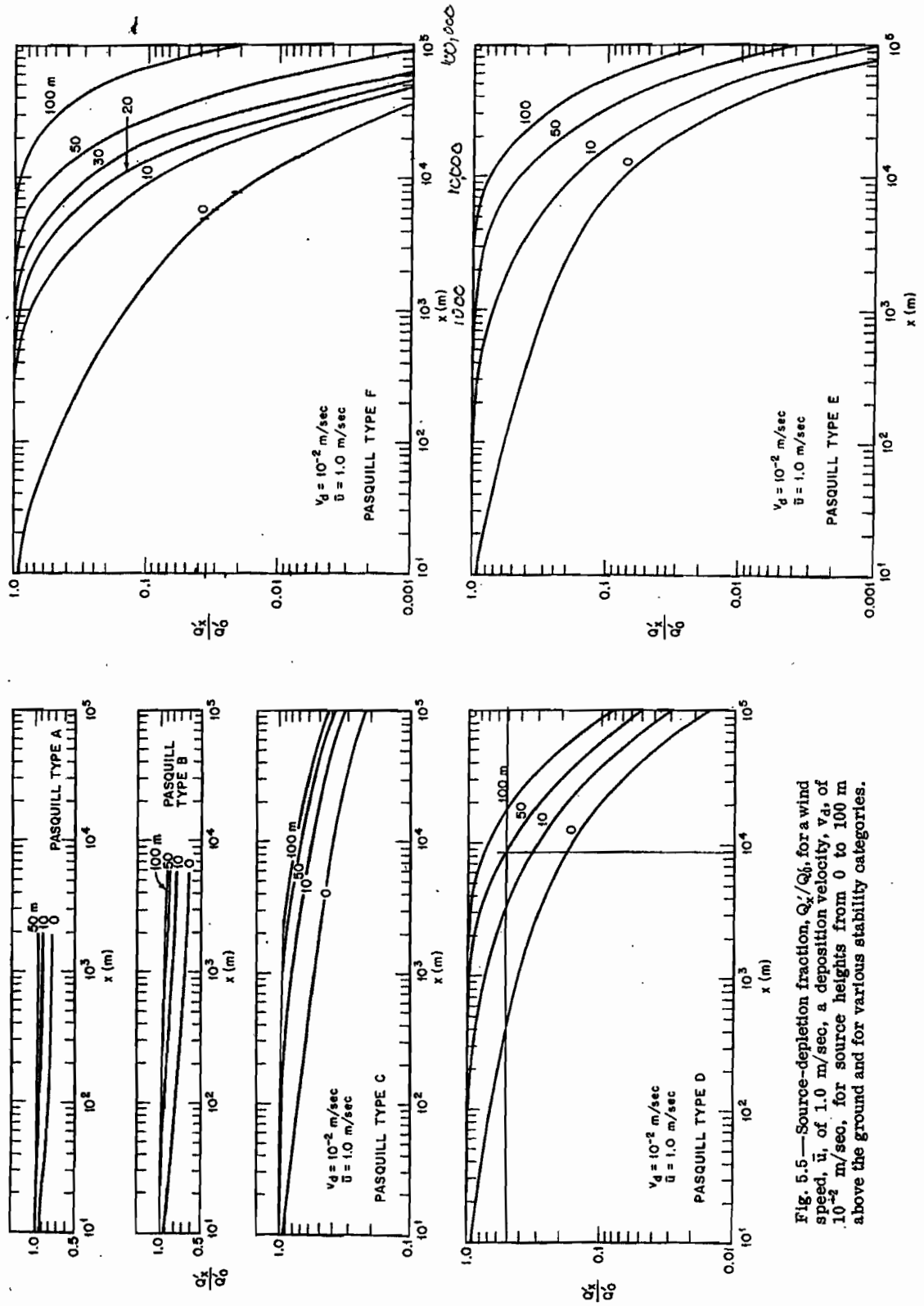

Fig. 5.5—Source-depletion fraction, Q_x'/Q_0', for a wind speed, $\bar{u}$, of 1.0 m/sec, a deposition velocity, v_d, of 10^{-2} m/sec, for source heights from 0 to 100 m above the ground and for various stability categories.

$$\left(\frac{Q'_x}{Q'_0}\right)_2 = \left(\frac{Q'_x}{Q'_0}\right)_1^{\bar{u}_1 v_{d2}/\bar{u}_2 v_{d1}} \tag{5.49}$$

where the subscript 1 refers to values found in Fig. 5.5 and the subscript 2 refers to the desired values. Thus, for example, to find the depletion fraction at a distance of 10^4 m for a source 50 m high, a $\bar{u}_2$ of 1 m/sec, a v_{d2} of 0.1 cm/sec, and a type F diffusion category, first find, in Fig. 5.5, the value of $(Q'_x/Q'_0)_1$ for h = 50 m, x = 10^4 m, $\bar{u}$ = 1 m/sec, and v_d = 1 cm/sec: $(Q'_x/Q'_0)_1 = 0.50$. Now substitute this value in Eq. 5.49,

$$\left(\frac{Q'_x}{Q'_0}\right)_2 = (0.50)^{0.1} = 0.93$$

The Chamberlain and the generalized Gaussian depletion models assume that the shape of the concentration profile in the vertical is unaltered by deposition. In an approach suggested by Calder (1961), K theory diffusion equations (see Chap. 3, Sec. 3-2.1.2) were used to describe the effect of deposition on a plume. In models of this type, the reduction of concentration caused by removing material from the cloud is not distributed evenly through the depth of the cloud but depends upon the profile of vertical mixing. Therefore the shape of the vertical profile of concentration will change as the computation proceeds. Smith (1962a) schematically illustrates the effect for a case where h = 0, $v_g = 0$, $v_d > 0$, and the exchange coefficient is constant with height. The net result is a more rapid depletion of the bottom portion of the plume; so downwind from the source the height of the maximum concentration is above the surface and increases in the downwind direction. Definitive field measurements to evaluate the statistical depletion model and the K-theory depletion model are not yet available. Computations show that the statistical models (Eqs. 5.42 and 5.48) give higher depletion factors than the K-theory models under stable conditions.

5-3.2.3 Deposition Measurements. Among the important measurements of the deposition of radioactive vapors and aerosols are the pioneering efforts of Chamberlain (1960) at Harwell. He was concerned with the fission products formed in reactors or by nuclear detonations. The isotope ^{131}I was one of the more important fission products studied. Although liberated as a vapor, ^{131}I is thought also to be adsorbed on condensation nuclei which are too small to have an appreciable gravitational settling velocity but which, nevertheless, deposit on surfaces under electrostatic, chemical, and other physical forces. Chamberlain's ^{131}I-vapor-release experiments were conducted both in the wind tunnel and in the free atmosphere and included simultaneous air concentration and deposition measurements on natural and simulated leaves and grass and on filter paper.

Recently, a series called Controlled Environmental Radioiodine Tests (Hawley, Sill, Voelz, and Islitzer, 1964) was conducted at the National Reactor Testing Station in Idaho to trace the radioiodine through the air–vegetation–cow–milk–human chain. The field results of both the Harwell and Idaho tests are summarized in Table 5.9a, which gives the existing meteorological conditions and the computed (from Eq. 5.41) deposition velocities for various collection surfaces. Similar results on the deposition of ^{131}I were obtained by Convair (1959, 1960) from the Fission-products Field Release Test I held in Idaho (NRTS) and Test II held in Utah (Dugway). Results are summarized in Table 5.9b. Chamberlain (1959) further computed an ^{131}I deposition velocity averaging 0.4 cm/sec on grass for the Windscale accident; Islitzer (1962) computed 0.2 cm/sec on sagebrush for the SL-1 accident, which occurred in the winter.

From these results one would conclude that the dry-deposition velocity of ^{131}I ranges over an order of magnitude and is dependent, to a large extent, upon the characteristics of the vegetation and ground surface. It is not clear if or how wind speed, thermal stability, or atmospheric turbulence affects the velocities. It is also possible that downwind distance has an effect because of a physical change in the iodine, for example, from a vapor to an aerosol. At present, without really having any information on the physical processes involved in the dry deposition of ^{131}I upon natural surfaces, a value of 2.0 cm/sec for grass or water surfaces appears appropriate as an average maximum, and somewhat smaller values ranging down to 0.5 cm/sec, for soil and snow surfaces.

The Convair (1959, 1960) studies essentially involved the release and downwind measurement of various radioactive isotopes from irradiated metallic reactor fuel elements, including isotopes of iodine, cesium, ruthenium,

Table 5.9a—SUMMARY OF ^{131}I DEPOSITION FIELD EXPERIMENT RESULTS*

	Harwell tests							Idaho tests		
	1	2	3	4	5	6	7	I	II	Snow
Deposition velocity, cm/sec										
Grass	1.9	2.6	1.8	3.7	1.7	1.8	1.1	0.6	1.0	
Soil								0.8	0.4	
Snow										0.2
Carbon								0.6	0.7	0.9
Clover leaves			1.3	0.9	0.5		0.3			
Paper leaves			2.0	1.5	1.0		0.6			
Filter paper	0.6	0.7	0.9	0.6	0.3					
Sticky paper								0.2	0.4	0.6
Wind speed, m/sec	5.2	4.3	5.2	4.1	1.6	2.3	3.9	7.1	9.3	6.0
Friction velocity, cm/sec	48	35	48	38	15	20	26	61	69	50
Roughness length, cm	2.8	1.5	1.2	2.4	2.4	5.0	1.0	3.1	1.5	2.1
Downwind distance, m	15	20	20	20	20	100	100	300	375	340
Grass cover, g/m²	500	200	260	420	420	610	420	153	246	Snow cover
Stability	Lapse	Neutral	Lapse	Lapse	Neutral	Lapse	Neutral	Lapse	Lapse	Stable

*Chamberlain, 1960, and Hawley, Sill, Voelz, and Islitzer, 1964.

Table 5.9b—SUMMARY OF CONVAIR ^{131}I FIELD RELEASE TESTS*

	E	F	H	1	2	3	4	5	8	10	11
Deposition velocity, cm/sec											
Grass				2.1†						1.2‡	
Soil	0.5	1.4	0.5								
Sticky paper	1.1	0.7	1.5	0.4	0.3	0.1	0.2	0.2	0.3	0.2	0.6
Water	1.8†	2.3†	1.4†								
Wind speed, m/sec	6.8	5.3	4.0	5.0	4.2	3.2	2.4	4.4	2.7	2.6	4.4
Downwind distance, m	1,600	1,600	1,600	32,000	1,000	1,000	1,000	4,000	1,000	4,000	16,000
Stability	Lapse	Lapse	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable

*Convair, 1959, 1960.
†Downwind distance of 2000 m.
‡Downwind distance of 1000 m or less.

zirconium, cerium, niobium, and tellurium for which deposition-velocity calculations were made. Meteorological conditions included both adiabatic and stable lapse rates, and measurements of ground deposition and air concentrations were made to distances of 3200 m. Some sticky-paper measurements were made out to 3.2×10^4 m. All particles were less than 10 μ in diameter. Table 5.10 summarizes the deposition-velocity calculations. Note that these values are averages and that there is considerable scatter in the data which cannot be explained by the meteorological parameters that were measured. For example, the average deposition velocity of 0.2 cm/sec for ^{137}Cs on a grass surface was computed from 21 values ranging from 0.04 to 0.4 cm/sec.

Table 5.10—SUMMARY OF CONVAIR RADIONUCLIDE FIELD RELEASE TEST DEPOSITION VELOCITIES

	Deposition velocities, cm/sec			
	Water	Soil	Grass	Sticky paper
^{137}Cs	0.9 (5)*	0.04 (15)	0.2 (21)	0.2 (117)
^{103}Ru	2.3 (9)	0.4 (16)	0.6 (20)	0.4 (98)
^{95}Zr, ^{95}Nb	5.7 (6)	2.9 (6)		1.4 (10)
^{141}Ce				0.7
^{127}Te, ^{129}Te				0.7 (8)

*Number in parentheses indicates the number of determinations.

Another technique used in calculating deposition velocities is material-balance measurements such as performed by Islitzer and Dumbauld (1963) in their fluorescent-particle studies. The technique involves the determination of the mass flux of material through a vertical plane perpendicular to the mean wind direction. The downwind decrease of this flux is attributed to a material loss through deposition. Using uranin particles with a median diameter of 1 μ and a fall velocity of less than 10^{-2} cm/sec, Islitzer and Dumbauld computed deposition velocities of 0.2, 2.4, and 7.1 cm/sec for inversion, neutral, and lapse conditions, respectively, for the arid terrain in Idaho. From data presented by Simpson (1961), these authors also computed a value of 0.5 cm/sec for four stable cases with zinc sulfide submicron particles over similar terrain at Hanford, Wash. These and other deposition data are quoted in a summary article by Gifford and Pack (1962).

Two conclusions seem apparent from the available field data on the deposition of vapors and submicron particles, i.e., that chemically active materials such as ^{131}I deposit more readily than inactive materials such as ^{137}Cs or nonradioactive fluorescent particles and that vegetation surfaces such as grasses and bushes provide removal rates that are greater than bare surfaces. At present, however, what effects atmospheric transport and diffusion parameters have upon deposition or what effect more complex surfaces, such as buildings and forests, have upon deposition rates is not clear.

5-4 THE CALCULATION OF PRECIPITATION SCAVENGING (Rudolf J. Engelmann)

5-4.1 Introduction

The scavenging process has three major divisions: (1) delivery or transport of the material to the scavenging site, (2) in-cloud scavenging by the cloud elements and precipitation, here called rainout and snowout, and (3) below-cloud scavenging by the precipitation, here called washout. Material from low-elevation sources will be transported with the low-elevation winds and diffused upward by low-level turbulence. Once in the vicinity of clouds it may be carried into those clouds by organized vertical motions. When the material is from high elevations (the stratosphere), the general circulation of the earth's atmosphere and the exchange mechanism at the tropopause have control of the delivery.

There are several good starting points for the study of scavenging. Junge (1963) and Facy (1962) have looked at in-cloud scavenging but with differing conclusions. Fletcher (1962) and Mason (1957) have published texts on precipitation and cloud physics with comprehensive bibliographies. Chamberlain (1953) appears to have attempted the first broad application of scavenging equations, and his approach is still used. Fuchs (1964) has presented an extensive volume on the mechanics of aerosols. Reiter (1964) and Danielsen (1964) serve as introductions to the controversy on stratosphere–troposphere exchange. There is increasing interest in the scavenging problem, and the reader should be alert for the very probable future measurements of rain spectra, washout coefficients, scavenging efficiencies, and other parameters discussed later in the section.

List of Symbols

Symbols used frequently in Sec. 5-4 on precipitation scavenging are listed here. (The dimensions mass, length, time, and temperature are abbreviated as M, L, T, and D, respectively. The equation or section number indicates the first appearance of the symbol.)

A	Cross-sectional area of drop of diameter D (L^2), Eq. 5.54
a	Particle radius (L), Eq. 5.52
D	Drop diameter (the collector) (L), Eq. 5.52
d	Particle diameter (the collected) (L), Eq. 5.56
E	Scavenging efficiency (dimensionless), Eq. 5.53
F	Flux density of drops (drops/area-time-diameter interval), Eq. 5.54
K	Impaction parameter or Stokes number (dimensionless), Eq. 5.52
k_1	Concentration of contaminant in cloud water (M/L^3), Eq. 5.60
L/ρ	Fraction of cloud space filled with liquid water (dimensionless), Eq. 5.60

M	Mass of aerosol particle of diameter d (M), Eq. 5.56
N	Concentration of drops in air (drops/volume-diameter interval), Eq. 5.55
Q, Q′	Plume source strength (M, M/T), Eq. 5.62
Re	Reynolds number of waterdrop (dimensionless), Eq. 5.58
Sh	Nusselt diffusion number or Sherwood number (dimensionless), Eq. 5.57
T	Age of cloud (T), Eq. 5.61
t	Time (T), Eq. 5.50
U	Obstacle (raindrop) speed (L/T), Eq. 5.52
$\bar{u}$	Average value of the wind component in the direction of the mean horizontal vector wind (L/T), Eq. 5.64
Y	Diffusivity of a vapor in air (L^2/T), Eq. 5.57
α	Radioactivity per mass of particle (curies/g), Eq. 5.56
ϵ	Rainout efficiency, $1-(\chi/\chi_0)$ (dimensionless), Eq. 5.60
Λ	Washout coefficient (T^{-1}), Eq. 5.51
μ	Dynamic viscosity of air (M/LT), Eq. 5.52
ν	Kinematic viscosity of air (L^2/T), Eq. 5.58
ρ	Density (M/L^3), Eq. 5.52
σ_θ	Standard deviation of horizontal-wind-direction distribution (radians), Sec. 5-4.11
σ_y	Standard deviation of plume concentration in the crosswind direction (L), Eq. 5.62
χ	Concentration of contaminant in air (M/L^3), Eq. 5.50
χ_0	Concentration at start of scavenging (M/L^3), Eq. 5.50
Ψ	Rainout coefficient (T^{-1}), Eq. 5.50
ω	Deposition rate by washout or total deposition in accordance with dimensions of Q′ or Q (M/L^2T or M/L^2), Eq. 5.62

5-4.2 Specification of the Problem

Quite obviously the intensity and location of the clouds and precipitation will determine the potential for scavenging and can usually be stated explicitly. However, fine details of the clouds and precipitation, such as entrainment, electrical charge, and snow-crystal shape, are also important but generally impossible to specify.

The nature of the material to be scavenged is fully as important as the nature of the precipitation and should be specified as to size, if particulate, and to solubility, if gaseous. Density is important for at least the larger particles. Characteristics of electrical charge and wettability can be quite important, and these effects are yet under debate and investigation. With increasing time and distance from the source, all these characteristics are modified by agglomeration and by attachment and adsorption onto natural aerosols. The material should then assume the nature of this host.

Now the natural aerosol is not a well-defined parameter either, varying with elevation, geography, and meteorology. In his extensive treatment of natural aerosols, Junge (1963) presents model size distributions that may be used in the absence of local measurements (Fig. 5.6). Although little is known about the density of natural aerosols, Junge concludes, from chemical composition, that most have densities of 1.0 to 2.0 g/cm^3.

The scavenging process consists of repeated exposures of particles and gases to cloud or precipitation elements with some chance of collection on the element for each exposure. The scavenging is, consequently, an exponential decay process obeying the equations

$$\chi = \chi_0 \exp(-\Psi t) \tag{5.50}$$

$$\chi = \chi_0 \exp(-\Lambda t) \tag{5.51}$$

where Ψ and Λ are called the rainout and washout coefficients, respectively. Because these coefficients are dependent upon many aerosol and scavenger characteristics, it is easier and generally as accurate to begin the solution of a problem by adjustment or modification of previously measured or predicted coefficients than with the more basic variables.

Note that Eqs. 5.50 and 5.51 and other equations in this section apply to instantaneous and space-averaged concentration fields but cannot apply to time-averaged concentrations since time is here used as an independent variable.

5-4.3 The Theory of Washout by Rain

When an obstacle (such as a raindrop) falls, it sweeps out a volume of air. This volume of air

APPENDIX F

MONTANA MODELING CHECKLIST

Montana's Air Quality Modeling Checklist

1. Name of applicant Mines Management Inc.
   Name of facility Montanore Mine Project

2. Permit no. _____

3. UTM coordinates of facility: UTM Easting 603,779 UTM Northing 5,329,448
   Zone 11 Elevation 1328 m Air Quality Control Region:

   (coordinates of mill area source 1 provided)

4. Name of applicant's modeling contact/consultant Susan Connell, TRC Environmental Corporation
   Phone number of applicant's modeling contact/consultant (307) 742-3843 or (308) 764-2550

5. Date of initial contact with DEQ modeling staff 2/28/05
   Name of modeling contact John Coefield
   Type of contact (include dates):
   Phone 2/28, 5/12, 10/13 _____
   Written 6/20, 9/27, 12/12 _____
   Meeting none _____

6. Was a written modeling protocol submitted to MDEQ? Yes X _____ No _____
   If yes, what date was protocol submitted? September 27, 2005 _____

7. Is the proposed facility/modification located in a nonattainment area? Yes X ____ No _____
   If yes, for what pollutants? Load-out facility in Libby will be located within PM10 and PM2.5 nonattainment area. Mine and surface facilities are not located within a nonattainment area. _____

8. Has an Emission Summary Table been submitted? Yes X _____ No _____

9. Do modeled emissions agree with requested maximum permitted emission levels?
   Yes X _____ No _____

10. Were all existing and proposed emissions from this source included in the analysis?
    Yes X _____ No _____

11. Is a plot plan summary showing UTM coordinates and the following items included with the analysis? Yes X _____ No _____
    Emission Release Locations Yes X _____ No _____

Nearby Buildings	Yes X _____	No _____
Property Lines	Yes X _____	No _____
Fence Lines/ Areas of Controlled Access	Yes X _____	No _____
Roads	Yes X _____	No _____
UTM Coordinates (shown on axes)	Yes X _____	No _____
Cross Section Directions	Yes X _____	No _____

12. Are topographic maps showing the following items included with the analysis?

Source Locations	Yes X _____	No _____
Contour Lines	Yes X _____	No _____
Receptor Locations	Yes X _____	No _____
Maximum Impact Locations	Yes X _____	No _____
UTM Coordinates	Yes X _____	No _____

13. Are cross-section diagrams included with the analysis? Yes X _____ No _____

Showing buildings and stacks	Yes X _____	No _____
At least 2 cross-sections at right angles	Yes _____	No X _____

(available in paper copy upon request)

Supporting photographs of cross-sections (if an existing sources)

Yes _____ No _____

14. Are all stack heights at or below GEP stack height? Yes X _____ No _____

Are downwash input and output files submitted?	Yes X _____	No _____
Table of building heights included in report?	Yes X _____	No _____

15. Model Selection
    a. Terrain modeled: Simple _____ Intermediate _____ Complex X_____
    b. Models used, version number:
       SCREEN3 _____
       T-SCREEN _____
       ISC3 02035 _____
       AERMOD _____
       VISCREEN _____
       PLUVUEII _____
       CALPUFF * 5.711a _____
       * If using CALPUFF, refer to the CALPUFF Modeling Checklist.
    c. Were other models used? Yes _____ No X_____

If so, which model(s) was used? _____
Why? _____

d. Was building downwash modeled? Yes X _____ No _____

If so, which downwash program was used? BPIP _____
Why? It is the regulatory program approved for use with ISCST3 _____

16. Do the model-input options elected for the analysis agree with EPA's ***Guideline on Air Quality Models***? Yes X _____ No _____
If no, explain options used, and why they were selected in report.

17. Was deposition modeled near the facility? Yes _____ No X _____

18. Was the Rural land use designation used in the analysis? Yes X _____ No _____

19. Meteorology
    a. Was screening meteorology used? Yes _____ No X _____
       i. If yes, for simple terrain impacts, was the full meteorology array used? Yes _____ No _____
       ii. If yes, was the neutral/unstable mixing height set equal to 1 m above plume height (with a minimum of 320 m)? Yes _____ No _____
       iii. If yes, do the screening wind directions include the 36 radials plus "line up" directions (with corresponding receptors for each wind direction)? Yes _____ No _____

    b. Was actual meteorological data used? Yes X _____ No _____
       If yes, where was the meteorological data collected?
       i. Surface Site: Ramsey Creek Monitoring Site _____
          UTM Easting 603,980_____ UTM Northing 5,329,726_____
       ii. Upper Air Site: Spokane, WA _____
          UTM Easting _____ UTM Northing _____
       iii. Who did you contact within the Department regarding the adequacy of using this data? Eric Thunstrom / John Coefield When? Modeling Protocol 9/27/05
       iv. Is a Wind Rose illustrating the data provided? Yes X____ No ____ Page No: Protocol Figure 6
       v. Did you document periods of missing data and how were they filled in? Yes X No Report Page: Protocol Page 6
       vi. How many years of meteorological data were used in the analysis? 1 _____
       vii. Meteorological years used 88-89_____

20. Receptors
    a. Were actual terrain elevations used for each receptor? Yes X _____ No _____
       If yes, what was the source and scale of the terrain elevations?
       (e.g., 7.5' USGS maps, 1:24,000 DEM data, 1:250,000 DEM data) 1:24,000 DEM
    b. Were Cartesian (gridded) receptors used (required when modeling > 1 stack) Yes X _____ No_____

c. If coarse modeling was performed, were receptors spaced no further apart than 500 m?

Yes X _____ No_____

d. Do receptors extend far enough to include the maximum impact location and the nearest terrain at Stability F 2.5 m/sec plume height? Yes X _____ No_____

e. Was a fine mesh of receptors (spaced no further apart than 100 meters) used to define the maximum impact areas for all averaging times? X _____ Yes_____ No

f. Were receptors placed no further than 50 meters apart along the fence line?

Yes X _____ No_____

g. Were there steep terrain areas that required denser receptor spacing?

Yes _____ No X_____

h. Were receptors removed inside fenced areas of plant property?

Yes X _____ No_____

21. Impact Analysis Summary

a. Were the modeling results summarized for each pollutant and for each averaging period?

Yes X _____ No_____

b. Are maximum impacts compared against NAAQS, MAAQS, and PSD increments?

Yes X _____ No_____

c. Are the controlling meteorology conditions summarized? Yes X _____ No _____

d. Are the controlling receptor locations and elevations summarized?

Yes X _____ No_____

e. Were all existing and proposed emissions from this source included in the analysis?

Yes X _____ No_____

If no, why not? _____

f. Were ambient background levels included on the MAAQS/NAAQS analysis results?

Yes X _____ No_____

What was the source of the background information? MDEQ POS Letter Dated 12/12/05

g. Were impacts on PSD Class I areas evaluated in the analysis? Yes X____ No _____

Class I Area Name: Cabinet Mountains _____Closest Distance: 1.3 km_____

Class I Area Name: _____Closest Distance:_____

Class I Area Name: _____Closest Distance:_____

22. PSD Sources Not Applicable
    a. Were other Air Quality Related Values addressed? Yes _____ No _____
    b. Was a visibility analysis performed for any Class I area? Yes _____ No _____
    c. Was a regional haze analysis performed for any Class I area? Yes _____ No _____
    d. Was it necessary to include the impact of other contributing sources on the analysis? Yes _____ No _____
    e. If yes, were those sources included on the Emissions and Stack Parameters Summary? Yes _____ No_____

23. Have you included input, output, meteorological data, and technical support files along with a detailed description of these files on or CDs or DVDs with your modeling analysis submittal? Yes X _____ No _____
    a. Are you submitting the following data on diskettes? Yes X _____ No _____
    b. BPIP input/output? Yes X _____ No_____
    c. EPA Dispersion model input ready for execution? Yes X _____ No_____
    d. Dispersion model output Yes X _____ No_____
    e. Meteorological data (in ASCII format)? Yes X _____ No_____
    f. Post processing programs & files? Yes X _____ No_____
    g. Emissions and maximum impact summary tables? Yes X _____ No_____

APPENDIX G

ELECTRONIC FILES

Appendix C - Electronic Files
Montanore Mine Project
Electronic File Index

Model Files

INPUT FILE NAME	OUTPUT FILE NAME	POLLUTANT	AVERAGING PERIOD	MET DATA	RECEPTOR SET	PLOT FILENAMES
NOXAC1.INP	NOXAC1.OUT	NOX	ANNUAL	RAMSEY.ASC	CLASS I RECEPTORS	NOXAC1.PLT
NOXAC2.INP	NOXAC2.OUT	NOX	ANNUAL	RAMSEY.ASC	CLASS II RECEPTORS	NOXAC2.PLT
NOXSTC1.INP	NOXSTC1.OUT	NOX	24 HR.	RAMSEY.ASC	CLASS I RECEPTORS	NOX1C1.PLT
NOXSTC2.INP	NOXSTC2.OUT	NOX	24 HR.	RAMSEY.ASC	CLASS II RECEPTORS	NOX1C2.PLT
PM10AC1.INP	PM10AC1.OUT	PM10	ANNUAL	RAMSEY.ASC	CLASS I RECEPTORS	PM10AC1.PLT
PM10AC2.INP	PM10AC2.OUT	PM10	ANNUAL	RAMSEY.ASC	CLASS II RECEPTORS	PM10AC2.PLT
PM10STC1.INP	PM10STC1.OUT	PM10	24 HR.	RAMSEY.ASC	CLASS I RECEPTORS	PM1024C1.PLT
PM10STC2.INP	PM10STC2.OUT	PM10	24 HR.	RAMSEY.ASC	CLASS II RECEPTORS	PM1024C2.PLT
PM25AC1.INP	PM25AC1.OUT	PM2.5	ANNUAL	RAMSEY.ASC	CLASS I RECEPTORS	PM25AC1.PLT
PM25AC2.INP	PM25AC2.OUT	PM2.5	ANNUAL	RAMSEY.ASC	CLASS II RECEPTORS	PM25AC2.PLT
PM25STC1.INP	PM25STC1.OUT	PM2.5	24 HR.	RAMSEY.ASC	CLASS I RECEPTORS	PM2524C1.PLT
PM25STC2.INP	PM25STC2.OUT	PM2.5	24 HR.	RAMSEY.ASC	CLASS II RECEPTORS	PM2524C2.PLT
SO2AC1.INP	SO2AC1.OUT	SO2	ANNUAL	RAMSEY.ASC	CLASS I RECEPTORS	SO2AC1.PLT
SO2AC2.INP	SO2AC2.OUT	SO2	ANNUAL	RAMSEY.ASC	CLASS II RECEPTORS	SO2AC2.PLT
SO2STC1.INP	SO2STC1.OUT	SO2	1,3 HR.	RAMSEY.ASC	CLASS I RECEPTORS	SO23C1.PLT, SO21C1.PLT
SO2STC2.INP	SO2STC2.OUT	SO2	1,3 HR.	RAMSEY.ASC	CLASS II RECEPTORS	SO23C2.PLT, SO21C2.PLT
SO224C1.INP	SO224C1.OUT	SO2	24 HR.	RAMSEY.ASC	CLASS I RECEPTORS	SO224C1.PLT
SO224C2.INP	SO224C2.OUT	SO2	24 HR.	RAMSEY.ASC	CLASS II RECEPTORS	SO224C2.PLT
AS.INP	AS.OUT	AS	ANNUAL	RAMSEY.ASC	ALL	AS.PLT
CD.INP	CD.OUT	CD	ANNUAL	RAMSEY.ASC	ALL	CD.PLT
CR.INP	CR.OUT	CR	ANNUAL	RAMSEY.ASC	ALL	CR.PLT
PB.INP	PB.OUT	PB	ANNUAL	RAMSEY.ASC	ALL	PB.PLT
SB.INP	SB.OUT	SB	ANNUAL	RAMSEY.ASC	ALL	SB.PLT

CALPUFF Model Files

CALPUFF INPUT/OUTPUT
CALPPM10.INP PM10.LST
CALPPM25.INP PM25.LST

POSTUTIL INPUT/OUTPUT
POSTUTPM10.INP POSTUTPM10.LST
POSTUTPM25.INP POSTUTPM10.LST

CALPOST INPUT/OUTPUT
CPOSTPM10.INP CPSTPM10.LST
CPOSTPM25.INP CPSTPM25.LST

Meteorological Data Files

RAMSEY.ASC	1-Year On-site Meteorological Dataset
RAMSEYCP.ASC	1-Year On-site Meteorological Dataset with Extended Parameters for CALPUFF

BPIP Files

MONTGEN.INP	Montanore Project BPIP Input File - Mill Site Building
MONTGEN.OUT	Montanore BPIP Output File
MONTGEN.SUM	Montanore BPIP .SUM File

Production Emissions Inventory

Appendix C - Montanore Final Emissions Inventory.xls
WIND.FOR
WIND.EXE
MONTTAIL.OUT
RAMSEY.ASC (header line deleted)

Construction Emissions Inventory

Appendix D - Montanore Final Constr EI.xls

Construction Model Files

CSTNOXC2.INP CSTNOXC2.OUT

APPENDIX G

ELECTRONIC FILES

Appendix C - Electronic Files
Montanore Mine Project
Electronic File Index

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INPUT FILE NAME	OUTPUT FILE NAME	POLLUTANT	AVERAGING PERIOD	MET DATA	RECEPTOR SET	PLOT FILENAMES
NOXAC1.INP	NOXAC1.OUT	NOX	ANNUAL	RAMSEY.ASC	CLASS I RECEPTORS	NOXAC1.PLT
NOXAC2.INP	NOXAC2.OUT	NOX	ANNUAL	RAMSEY.ASC	CLASS II RECEPTORS	NOXAC2.PLT
NOXSTC1.INP	NOXSTC1.OUT	NOX	24 HR.	RAMSEY.ASC	CLASS I RECEPTORS	NOX1C1.PLT
NOXSTC2.INP	NOXSTC2.OUT	NOX	24 HR.	RAMSEY.ASC	CLASS II RECEPTORS	NOX1C2.PLT
PM10AC1.INP	PM10AC1.OUT	PM10	ANNUAL	RAMSEY.ASC	CLASS I RECEPTORS	PM10AC1.PLT
PM10AC2.INP	PM10AC2.OUT	PM10	ANNUAL	RAMSEY.ASC	CLASS II RECEPTORS	PM10AC2.PLT
PM10STC1.INP	PM10STC1.OUT	PM10	24 HR.	RAMSEY.ASC	CLASS I RECEPTORS	PM1024C1.PLT
PM10STC2.INP	PM10STC2.OUT	PM10	24 HR.	RAMSEY.ASC	CLASS II RECEPTORS	PM1024C2.PLT
PM25AC1.INP	PM25AC1.OUT	PM2.5	ANNUAL	RAMSEY.ASC	CLASS I RECEPTORS	PM25AC1.PLT
PM25AC2.INP	PM25AC2.OUT	PM2.5	ANNUAL	RAMSEY.ASC	CLASS II RECEPTORS	PM25AC2.PLT
PM25STC1.INP	PM25STC1.OUT	PM2.5	24 HR.	RAMSEY.ASC	CLASS I RECEPTORS	PM2524C1.PLT
PM25STC2.INP	PM25STC2.OUT	PM2.5	24 HR.	RAMSEY.ASC	CLASS II RECEPTORS	PM2524C2.PLT
SO2AC1.INP	SO2AC1.OUT	SO2	ANNUAL	RAMSEY.ASC	CLASS I RECEPTORS	SO2AC1.PLT
SO2AC2.INP	SO2AC2.OUT	SO2	ANNUAL	RAMSEY.ASC	CLASS II RECEPTORS	SO2AC2.PLT
SO2STC1.INP	SO2STC1.OUT	SO2	1,3 HR.	RAMSEY.ASC	CLASS I RECEPTORS	SO23C1.PLT, SO21C1.PLT
SO2STC2.INP	SO2STC2.OUT	SO2	1,3 HR.	RAMSEY.ASC	CLASS II RECEPTORS	SO23C2.PLT, SO21C2.PLT
SO224C1.INP	SO224C1.OUT	SO2	24 HR.	RAMSEY.ASC	CLASS I RECEPTORS	SO224C1.PLT
SO224C2.INP	SO224C2.OUT	SO2	24 HR.	RAMSEY.ASC	CLASS II RECEPTORS	SO224C2.PLT
AS.INP	AS.OUT	AS	ANNUAL	RAMSEY.ASC	ALL	AS.PLT
CD.INP	CD.OUT	CD	ANNUAL	RAMSEY.ASC	ALL	CD.PLT
CR.INP	CR.OUT	CR	ANNUAL	RAMSEY.ASC	ALL	CR.PLT
PB.INP	PB.OUT	PB	ANNUAL	RAMSEY.ASC	ALL	PB.PLT
SB.INP	SB.OUT	SB	ANNUAL	RAMSEY.ASC	ALL	SB.PLT

CALPUFF Model Files

CALPUFF INPUT/OUTPUT
CALPPM10.INP PM10.LST
CALPPM25.INP PM25.LST

POSTUTIL INPUT/OUTPUT
POSTUTPM10.INP POSTUTPM10.LST
POSTUTPM25.INP POSTUTPM10.LST

CALPOST INPUT/OUTPUT
CPOSTPM10.INP CPSTPM10.LST
CPOSTPM25.INP CPSTPM25.LST

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MONTTAIL.OUT
RAMSEY.ASC (header line deleted)

Construction Emissions Inventory

Appendix D - Montanore Final Constr EI.xls

Construction Model Files

CSTNOXC2.INP CSTNOXC2.OUT