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FINAL REPORT FOR OPEN BURNING DISPOSAL OPERATIONS AIR PATHWAY HEALTH
RISK ASSESSMENT ALLEGHENY BALLISTICS ROCKET CENTER WV
12/01/1996
SANDIA NATIONAL LABORATORIES

Final Report

**Allegany Ballistics Laboratory
Open Burning Disposal
Operations
Air Pathways Health Risk
Assessment**

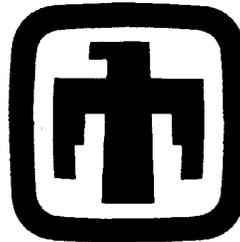
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Sandia National Laboratories

Exceptional Service in the National Interest

Abstract

Results from an air-pathways, health risk assessment are reported in this document for energetic material open burning disposal operations currently being carried out at a burning ground operated by Alliant Techsystems at the Allegany Ballistics Laboratory for the US Navy. Burning scenarios include the combustion of both pure propellant and explosives and the combustion of propellant- and explosive-contaminated waste products such as sawdust, other cellulosic material and miscellaneous plastic material. Emissions characterization of waste, typically encountered at the burning ground, was conducted at a specialized testing facility at Sandia National Laboratories to derive emission factors for use in dispersion modeling. Puff and continuous plume dispersion models, that took local topography into account, were used to evaluate off-site plume impacts for a long list of potentially toxic target species. Worst-case screen modeling and additional in-depth modeling results, using both worst-case screening meteorological data and on-site meteorological data, indicate that off-site exposure levels to hydrogen chloride are at or below applicable acute exposure criteria. Risk characterization for an extensive list of other target compounds including lead, benzene, dioxin and other carcinogens indicates all risk levels below EPA-prescribed target risk levels for all expected burn activities at the existing or proposed alternate ABL burn sites.

Explanatory and Technical Notes to the Reader

The work documented in this integrated final report was conducted in two phases. The period of performance for Phase 1 was November 1994 through January 1996 and consisted of open burning combustion products characterization, emissions factors development, and preliminary screening analyses. Results of Phase 1 were issued in a Review Draft Report dated January 1996. The period of performance for Phase 2 was February 1996 through December 1996 and consisted of final analysis work. A Report Addendum containing Phase 2 results only was issued in July 1996. This final report integrates the results of, and supersedes and replaces the two previous reports.

On November 8, 1995, the Department of the Navy, Naval Sea Systems Command, and Alliant Techsystems Inc., Aerospace Systems, signed a Consent Order with The State of West Virginia Division of Environmental Protection, Office of Air Quality. In Section 1.B of Part III Compliance Program, it was agreed the open burning of all P/E contaminated waste at ABL would cease on or before May 31, 1996. Open burning of P/E contaminated waste at ABL was terminated on or before May 31, 1996. Therefore, the low burn rate scenario mentioned in this report is no longer germane for P/E contaminated waste. Additionally, subparagraph 2.3.3.2 of this document cites a maximum burn limit of 500 pounds/day for P/E contaminated wastes. The current limit is 0 pounds per day, given the cessation of open burning of P/E contaminated waste. The waste stream consisting of double base propellant (containing nitrate ester and nitramine) in acetone absorbed in sawdust resulting from cleaning of mold parts has been determined to react as an explosive and has been reclassified as an explosive waste. A companion Ecological Risk Assessment has been completed and reported by others. In reading this report and its conclusions, the reader should keep in mind that any references contrary to the conditions or changes stated above, which may appear in the original work contained herein, should be taken in their historical context.

Abbreviations

ABL - Allegany Ballistics Laboratory
ACGIH - American Conference of Governmental Industrial Hygienists
AGL - above ground level
ATDM - All Terrain Dispersion Model
ERPG - Emergency Response Planning Guideline
FT-IR - Fourier Transform Infrared Spectroscopy
GC-FID - Gas Chromatography - Flame Ionization Detection
GC-MS - Gas Chromatography - Mass Spectroscopy
HEAST - Health Effects Summary Tables
HMX - Homocyclonite or Octogen (cyclotetramethylene tetranitramine)
HQ - Hazard Quotient
HTPB - Hydroxy-terminated Polybutadiene
ICP-AAS - Inductively Coupled Plasma Atomic Absorption Spectroscopy
IDLH - Immediately Dangerous to Life or Health
IRIS - Integrated Risk Information Systems
MSL - Mean Sea Level
NAAQS - National Ambient Air Quality Standard
NIOSH - National Institute of Safety and Health
NOAEL - No Observable Adverse Exposure Level
OSHA - Occupational Safety and Health Administration
P/E - Propellant/Explosive
RBC - Risk Based Concentration
RDX - cyclonite (cyclo-1,3,5-trimethylene-2,4,6-trinitramine)
TNMHC - Total Non-Methane Hydrocarbons
USGS - United States Geological Survey
UTM - Universal Transverse Mercator

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1. INTRODUCTION

1.1 Statement of the Problem

The Allegany Ballistics Laboratory (ABL) manufactures propellants and explosives for various components in the US military arsenal. In 1995 it is estimated that about 206 metric tons of propellant and explosive (P/E) will be formulated at the ABL facility. Excess or waste propellant and explosive is also generated during various production and testing activities at the facility. Excess propellant and explosive (P/E) materials are disposed of by open burning methods at an established burning ground within the plant boundaries. Additionally, some P/E-contaminated waste is generated during production and is similarly treated at the burning ground. These wastes include mixtures of sawdust and acetone; wood products, various plastics and small amounts of P/E that originate during cleanup of the various mixing and blending machines at the facility.

Estimates for calendar year 1995 are that 38 metric tons of pure energetic materials including ammonium perchlorate rocket fuel, double base rocket propellant and plastic bonded explosive will be burned at the ABL burning ground. Additionally, 77 metric tons of P/E-contaminated waste materials including organic solvents, biomass, rubber and plastics will be similarly handled at the burning grounds. As a result of concerns over air emissions from burning ground operations, the Department of the Navy, Naval Sea Systems Command and Alliant Techsystems, Aerospace Systems, have signed a Consent Order with the State of West Virginia, Division of Environmental Protection, Office of Air Quality to conduct a comprehensive air pathways risk assessment of burning operations to determine the adequacy of existing burning ground control procedures in light of possible off-site human toxicological impacts. The Consent Order also calls for a companion ecological risk assessment to be conducted following the air pathways risk assessment in order to assess human toxicological effects and other ecological effects by exposure pathways other than air. The companion Ecological Risk Assessment has been conducted and reported by others.

This report describes the methodology and results of a health risk assessment for the various open burning procedures currently carried out at the ABL facility. The risk analysis described in this report is an analysis of the potential for adverse health effects in off-site population areas that may be periodically impacted by smoke emissions from the ABL burning ground. Since this is the first formal risk assessment for the ABL burning ground operations, it has been carried out in a two-phase process that includes a screening modeling approach using non site-specific worst case meteorology, followed by an in-depth modeling analysis using one year of on-site meteorological data.

1.2 Project Scope and Objectives

The scope of the initial phase of this project and its accompanying report includes a description of the methodology and results from an air pathways initial screening analysis of burning activities currently carried out at the ABL plant. The project goes beyond many similar risk assessment activities in the sense that a supporting

experimental program to measure pollutant emissions from ABL waste materials was carried out at a specialized testing facility at Sandia National Laboratories in Albuquerque, New Mexico.

Specific project objectives are listed below:

- Measure pollutant emission factors for the various types of P/E and P/E-contaminated waste currently handled at the ABL burning ground.
- Conduct a hazards identification of the pollutants measured during the experimental testing of the candidate waste streams and compile a target compound list for further hazards evaluation.
- Assess the target compound list in light of current toxicological understanding and compile risk based concentration levels for as many of the target compounds as possible.
- Define the local complex terrain in a format compatible for use with the puff and plume dispersion models selected for use in this study.
- Conduct air dispersion modeling using both puff and continuous release models using meteorological screening files in order to predict worst-case exposure conditions for the target compounds previously identified.
- Assess off site exposure potential for the target pollutants from dispersion modeling results and evaluate the results against risk-based pollutant concentration levels compiled from the literature. Compare worst-case off-site exposure levels to pre-established risk criteria for cancer-causing substances or pre-established no observable adverse exposure levels for non-cancer causing substances.
- Conduct limited on-site and off-site sampling for selected plume constituents in order to complement the modeling exercises conducted for the site burn operations.
- Make recommendations regarding further risk assessment efforts and burning ground procedural modifications.

1.3 Document Overview

This document is organized into nine sections that describe the various phases of the project. Section 1 gives a brief overview and statement of the problem. Section 2 describes the ABL facility and burning ground. Section 3 describes the methodology employed for hazard identification in this project and specifically deals with the measurement program carried out at the Sandia National Laboratories Air Emissions Test Chamber. Section 4 presents the results from the hazard assessment efforts. Section 5 describes the dose-response assessment for the various target analytes that were identified for further investigation. Section 6 outlines the methodology and results of the air dispersion analysis that was carried out using local ABL topography. Section 7 presents the air dispersion results in light of the risk criteria established in earlier sections. Finally, a summary is given in Section 8 followed by technical references in Section 9.

2. FACILITY, MATERIALS AND PROCESS DESCRIPTION

2.1 Manufacturing Facility Description

2.1.1 Plant Description

The ABL manufacturing facility is located in the northern section of Mineral County in northern West Virginia as shown in Figure 2-1. Much of the northern plant boundary is in fact the Potomac river, which also forms the border between the western panhandle of Maryland and eastern panhandle of West Virginia. As a result of the plant proximity to the state border, population areas potentially impacted by the ABL burn operations are encountered both in West Virginia and Maryland. The plant property encompasses approximately 650 hectares (1,600 acres) and includes both administrative offices and production, test and storage facilities. At the plant, propellant and explosive materials are formulated from raw materials and are cast, extruded or machined into various shapes required for missile rocket motors and explosive warheads. Additionally, qualification batches of various energetic materials are periodically formulated for performance testing and other material qualification testing. Many of these materials are ultimately sent to the burning ground for disposal.

2.1.2 Burning Ground Description

The ABL burning ground is located in the northern section of the plant property immediately adjacent to the Potomac River, as shown in an aerial photograph in Figure 2-2. The burning ground, immediately south of the Potomac river in the upper left center of the photograph, encompasses approximately 3.5 hectares (9 acres) and includes a total of eight burning pads. Currently six steel burn pans, as shown in Figure 2-3, are in place at the site, five of which are currently in use. Waste material is placed in the various burn pans and is ignited by burning ground personnel. Burning rates vary considerably and range from very high rates for the pure energetics with high surface to mass ratios to very slow rates for the P/E-contaminated wastes that contain appreciable quantities of sawdust and other cellulosic material.

2.2 Local Topography and Land Use

2.2.1 Topographical Features

By virtue of its location in the foothills of the Allegheny Mountains, the ABL facility is surrounded by hilly terrain. A three dimensional surface plot of the region surrounding the ABL plant is shown in Figure 2-3 with a view perspective from the southwest. Although not shown in the surface plot, the Potomac River flows northward along the western boundary of the ABL plant property. The river then turns toward the east and forms the northern border of the plant boundary, ultimately turning back in a northerly direction as it flows toward the city of Cumberland, Md. The burning ground, located on the flat terrain along the river is at an elevation of 215 m mean sea level (msl). Adjacent hilly terrain is found nearly all directions with the highest ridges, rising to 400-500 m msl directly to the northeast and east. The

slope is more gradual to the north and northwest; however. Ridge lines at altitudes nearing 300 m msl are observed in these directions as well. The local terrain is also depicted as a contour map with shaded contour intervals in Figure 2-5. Map coordinates in both Figures 2-4 and 2-5 are given in Universal Transverse Mercator (UTM) meters (Zone 13).

2.2.2 Land Use

Land use in the region is primarily a mixture of rural and suburban residential. Dairy cattle grazing occurs among low density residential areas to the north of the burning ground. Immediately to the south of the burning ground lie manufacturing and storage facilities with additional open space within plant boundaries further to the south. Higher population density is observed in several residential areas to the northwest of the burning ground, such as Triple Lakes and BelAir, about 2 km to the west-northwest, and Creasaptown, about 3.3 km northwest. Further north lies the town of Cumberland, MD with a population of approximately 35,000. This preliminary investigation is understood to be a screening assessment such that limited emphasis is given to land use, since worst case exposure conditions are of interest.

2.3 Waste Treatment Process Description

2.3.1 Energetic Materials Description

Four general classes of energetic materials are manufactured at the ABL facility and are routinely disposed of at the burning ground. A summary listing of the various constituents of each material is given in Table 2-1. Two classes of ammonium perchlorate based propellant, with and without aluminum, are manufactured along with a double base propellant and a plastic bonded explosive containing HMX and RDX. Table 2-2 gives the elemental content of each formulation in units of weight percent.

Figure 2-1 (Attached foldout) A map of the ABL facility and surrounding area. The burning ground is located at the far right of the map



Figure 2-2 Aerial photo of the ABL plant and surrounding land. The burning ground is located in the upper left center of the photo.

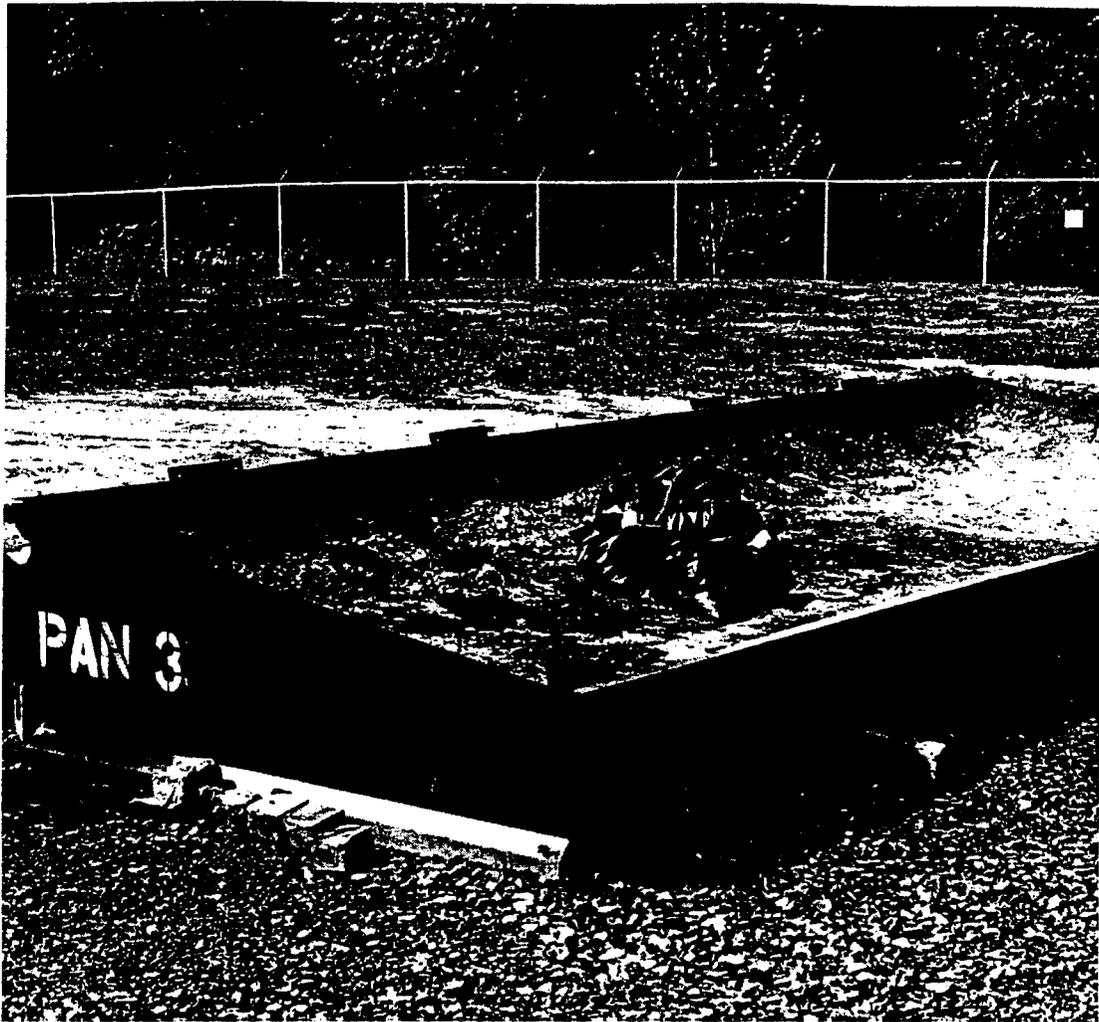


Figure 2-3 One of the six burn pans at the burning ground. The plant northern boundary fence, adjacent to the Potomac River, is in the background.

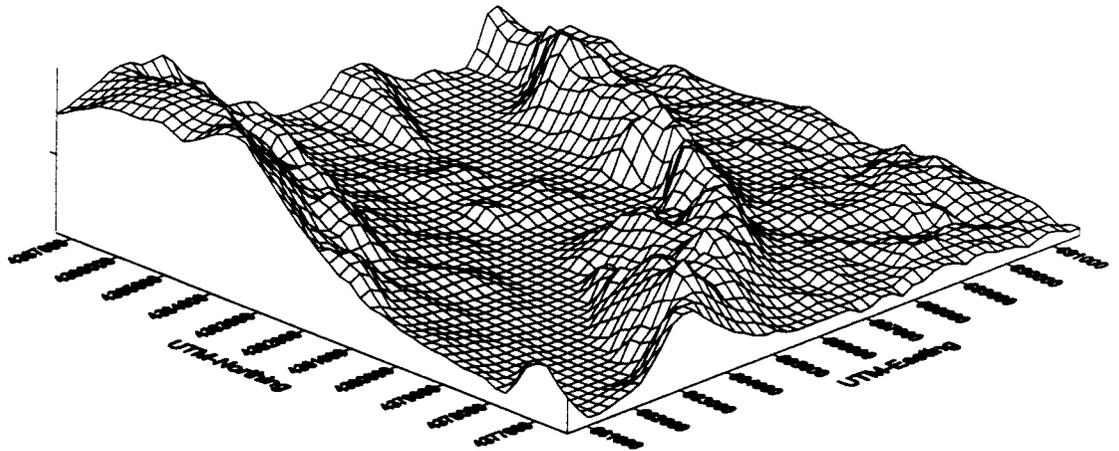


Figure 2-4 A 3-D surface showing the local terrain with a view perspective from the southwest. The burning ground is located in the approximate center of the surface.

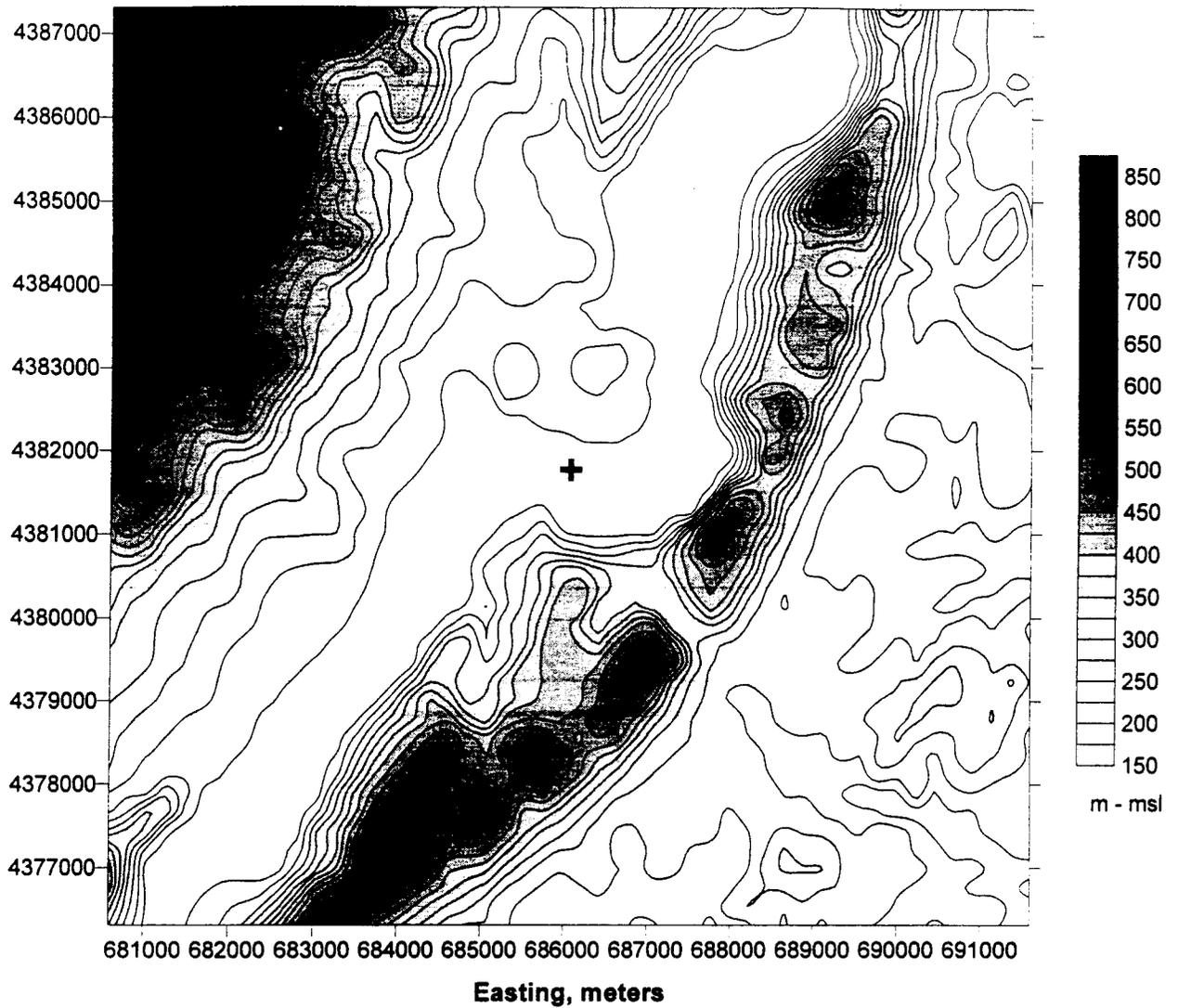


Figure 2-5 A topographical map of the ABL facility and adjacent land.. The burning ground location on the map is marked with the symbol.

Table 2-1 Generic Ingredient List for Pure Energetic Materials

Ingredient	Weight Percent
Aluminized Composite Propellant (Class 1.3)	
Aluminum	5-20
Ammonium Perchlorate	60-80
Polymer Binders and Nitro-Organic Compounds	9-15
Heavy Metals	<1
Non-Aluminized Composite Propellant (Class 1.3)	
Ammonium Perchlorate	83-88
Polymer Binders	11-16
Zirconium Salts	1
Double Base Propellants (Class 1.1)	
Nitramines (HMX and RDX)	60-65
Nitrate Esters (Nitroglycerine and Butanetrioltrinitrate)	25-27
Lead Salts	1-2
Zirconium Salts	1
Polymer and Misc. Nitro-organic Compounds	8
Metals (Bi and Sn)	<1
Plastic Bonded Explosive (Class 1.1)	
Nitramines (HMX)	64-82
Polymer Binders	~12
Plasticizers and Misc. Nitro-organic Compounds with Fe, S and Cu	~8
Aluminum	0-20

Table 2-2 Elemental Composition of Pure Energetic Materials

Element	Weight Percent			
	Al/Composite	Composite	Double Base	PBX
C	10.9	8.9	20.3	25.0
H	4.0	4.0	3.0	4.1
N	10.0	10.4	29.0	31.7
O	42.1	46.7	45.7	39.2
S	<0.1			0.1
Cl	21.7	25.8		
Fe	<0.1			<0.1
Al	10.0			
Zr		0.9	0.9	
Pb			0.9	
Bi			<0.1	
Sn				
Cu				<0.1

2.3.2 Miscellaneous Waste Material Description

In addition to pure energetics, a variety of miscellaneous waste material is also treated at the burning ground. These materials are termed Propellant/Explosive (P/E) contaminated waste and are generated during the handling of batch mixes of the various energetic materials manufactured at the plant. For example, cleanup of the various double base propellant mixing machines is carried out using acetone solvent along with sawdust as an adsorbent material. Acetone-sawdust mixtures are placed in sealed polyethylene bags and then transported to the burning ground where they are burned intact. Other items such as plastic gloves, tissues, swabs, tongue depressors, paint mixing sticks, fiber drums, plastic sheeting, tape and other material that has come into contact with the energetics are also termed P/E-contaminated waste and is disposed of by open burning as well. An estimated mass breakdown of the various miscellaneous materials by type is given in Table 2-3. The total estimated P/E-contaminated waste inventory for 1995 is 77 metric tons.

Table 2-3 Mass Breakdown of Miscellaneous Waste by Physical Category

Material Description	Weight Percent of Total Annual P/E-contaminated Disposal Mass
Miscellaneous Waste (55.4%)	
Paper Products	2.8
Wood Scraps	2.8
Wood Chips	16.6
Plastics (98% polyethylene, 2% Polyvinyl Chloride)	8.3
Cotton Rags	5.5
Fiber Drums/Cardboard	2.8
Other (plastic gloves, bags, etc.)	16.6
Energetic/Biomass/Solvent Waste (44.6%)	
Acetone	8.3
Acetone/Sawdust	37.9
Double Base Propellant	4.2
Explosive	7.1

2.3.3 Open Burning Process Description

2.3.3.1 Burn Mass Totals

Estimates of 1995 total mass consumption of P/E and P/E-contaminated waste are given in Table 2-4. These numbers are derived from estimates of scheduled plant production of the various pure energetics and are combined with information on the amount of waste that typically accompanies each type of production run. Waste production estimates were originally made in March 1995 and were updated in July 1995, since operations at a similar production plant in Texas were consolidated into the ABL operation following the sale of Hercules Aerospace ABL operations to Alliant Techsystems.

Table 2-4 Estimated Annual P/E and P/E-Contaminated Waste Disposal Inventory

Material	Estimated Annual Disposal Mass, kg
Pure Propellant/Explosive	
Non-Aluminized Composite Propellant	10,500
Aluminized Composite Propellant	15,800
Double Base Propellant	7,700
Plastic Bonded Explosive	4,200
P/E-contaminated Mix No. 1	
Sawdust	16,000
Acetone	4,500
Double Base	2,300
P/E-contaminated Mix No. 2	
Sawdust/Acetone	20,500
Explosive	3,900
Miscellaneous Debris	30,200

2.3.3.2 Burn Pan Mass and Frequency Limitations

Allegany Ballistics Laboratory has entered into a consent order agreement with the State of West Virginia, Office of Air Quality that specifies daily burn limits and frequencies. These mutually agreed upon burn limits are used as the starting point in this particular risk assessment. Daily burn pan limits for P/E waste are 445 kg (980 pounds) and for P/E contaminated waste are 227 kg (500 pounds). Burning ground procedures further allow a doubling of these limits per work day when unacceptable weather conditions for burning result in a backlog of material in the burning ground. Thus, a worst case daily burn scenario would be 1,000 kg of pure energetic materials and 500 kg of P/E-contaminated waste. Under the terms of the agreement with the State of WV however, this level of burn activity could be carried out only every other working day in order to remain in compliance with the overall burn pad daily limitations. As of May 31, 1996 P/E contaminated waste is no longer open-burned at ABL.

2.3.3.3 Burn Rates

Mass consumption or burn rates are required in each of the modeling scenarios considered in this risk assessment. To derive reasonable estimates of material burn rates we have used burn rate data from three sources namely: (1) estimates of burn rates for both P/E and P/E-contaminated waste from personnel observations during normal operations at the ABL burning ground; (2) measured burn rates of P/E-

contaminated waste at the SNL Wind-Shielded Combustion Facility (SWISH)¹; (3) measured burn rates of both P/E and P/E-contaminated waste at the SNL Air Emissions Test Chamber. The best measurements of burn rates available are from the SNL SWISH facility since a continuously operated load cell is used during test burns of material amounts similar to those burned at ABL under normal operations. The load cell gives a measure of total mass of combustible material during the burn so the mass loss per unit time can be readily calculated. Tests of only P/E-contaminated waste were conducted at this facility however, so estimates of burn rates of other materials were obtained from testing performed at the SNL Air Emissions Test Chamber. A load cell was not used in these smaller (< 5 kg) burns however, the starting and ending mass and the burn time was measured so that an overall rate could be determined. These numbers were supplemented with observations by personnel at the ABL burning ground during normal operations. The mass of a load in any particular burn pan is known, as is the approximate burn time so an estimate of burn rate can be made. Table 2-5 gives our best estimates of three burn rates used in three distinct air dispersion modeling scenarios that are more fully described in Section 6.5. The high burn rate is associated with pure energetics that have a high surface area to burn mass ratio. These burn rates are typically observed when the pure material to be burned is in chip or flake form. The medium burn rates are associated with all the pure energetic materials when they are in cast configurations, such as in large fiber drums or single large (> 20 kg) pieces. The lowest burn rates are encountered with P/E-contaminated waste. Since the amount of P/E material in these particular disposal mixtures is limited, the combustion rate of the biomass (sawdust, wood products, cotton rags) and other hydrocarbons is much like that observed in a smoldering wood fire.

Table 2-5 Burn Rate Estimates for Typical Waste Configurations

Waste Type	Burn Rate, g/s
Pure Energetic, Large Surface Area per Burn Mass	High, 5,000
Pure Energetic, Small Surface Area per Burn Mass	Medium, 200
P/E-contaminated Waste	Slow, 10

¹ SWISH is an acronym for the Sandia Wind Shielded Test Burner that is being investigated in a parallel ABL-Sandia project as a means of reducing smoke emissions during the combustion of P/E contaminated wastes at the ABL burning ground.

3. CHEMICAL HAZARD IDENTIFICATION METHODOLOGY

An important aspect of this particular risk assessment is that fact that an experimental program to measure emissions from waste streams encountered at the ABL facility is incorporated into the project. This approach yields a greater confidence in the overall assessment since the pollutant source term is directly referenced to a detailed measurement program at a specialized testing facility. The following sections more fully describe the rationale and methodology used in this project task area.

3.1 Approach and Rationale

In this study we have used a specialized testing facility at Sandia National Laboratories known as the Air Emissions Test Chamber to burn representative samples of the various waste forms encountered at the ABL facility in order to precisely document pollutant emission characteristics for the broad spectrum of chemicals that are likely to be encountered during such burning operations. This approach enables pollutant emission testing under controlled conditions and in a manner that yields pollutant emission factors² which can be used directly in various air dispersion models used to estimate pollutant concentrations at off-site receptors. An alternative approach for the determination of pollutant emission factors is to use data published in the technical literature, however little data is available for specific waste types since such a wide variety of energetic materials exist in the national waste inventory. Others have used combustion theory and thermodynamic models to predict pollutant emissions from various energetic materials, however many of these models are not fully validated and thus give pollutant emissions estimates with a high degree of uncertainty. Furthermore, such models do not yield credible estimates of the various trace level (parts per thousand and lower) species likely to be produced during combustion processes such as encountered at ABL. In light of these considerations, an experimental effort to measure emission from specific ABL waste streams was judged to be the best approach in defining a set of target pollutant and their associated emission factors.

3.2 Facility Description

The SNL Air Emissions Test Chamber consists of a large, air-supported, plastic-coated fabric dome inside which explosive detonations and propellant burns can be conducted without resulting damage to the structure. The chamber, shown in Figure 3-1, is a 15- m diameter hemispherical dome that is supported by a positive air pressure differential, maintained by a continuously operated electrical blower. Combustion or detonation tests, depending on the starting material, are carried out inside the chamber after which the emission products from the test are sampled and analyzed by a number of instruments positioned inside the chamber and immediately adjacent to the chamber in a mobile instrumentation van. A number of mixing fans are positioned inside the chamber so that the contents can be thoroughly mixed following a test. The chamber, whose internal volume is known, is tightly sealed

² An emission factor is a measure of the mass of a particular pollutant released per unit mass of starting material. The emission factor is typically expressed as a unitless ratio, for example, grams of pollutant released per gram of material consumed.

such that leakage of combustion products out of the chamber is minimal. The combination of a mixed and known chamber volume along with measured chamber dilution allows the combustion products from a particular test to be sampled, quantified and directly related to the starting mass of the test material in order to derive pollutant-specific emission factors.



Figure 3-1 The Air Emissions Test Chamber at Sandia National Laboratories in Albuquerque, New Mexico.

A collection of instruments were used in this test series to yield measurements of both gas and aerosol emission products from the various ABL waste compositions selected for testing. Table 3-1 lists the various sampling devices used in the testing program. A photo of the chamber interior showing some of the instrument used in the testing is shown in Figure 3-2.

Table 3-1 Instrument Systems Used in Chamber Testing

Instrument System	Pollutants Measured
Inside Chamber	
PM-10 Sampler with Quartz Filter	PM-10 Aerosol Conc.
PS-1 Sampler with Quartz Filter and Resin Cartridge	Semi-Volatile Organic Hydrocarbons
Low Flow Total Filter Sampler with Teflon Filter	Heavy Metal Aerosols
Low Flow Total Filter Sampler with Nylon Filter	Total Nitrate Gas/Aerosol
Low Flow Total Filter Sampler with Mixed Cellulose Ester Filter	Aluminum Aerosol
Low Flow Bubbler System	Total Chloride Gas/Aerosol
Open-Path FT-IR Spectrometer	HCl, NH ₃ , and other reactive gases
Aerodynamic Particle Sizer	Aerosol Size Distribution 0.5-30 micron particle diameter
Outside Chamber	
Continuous Gas Analyzers	CO, NOx, CO ₂ , SO ₂ Gas Concentration
Summa Canister	Volatile Organic Hydrocarbons
Closed Cell FT-IR Spectrometer	Reactive gases and hydrocarbons

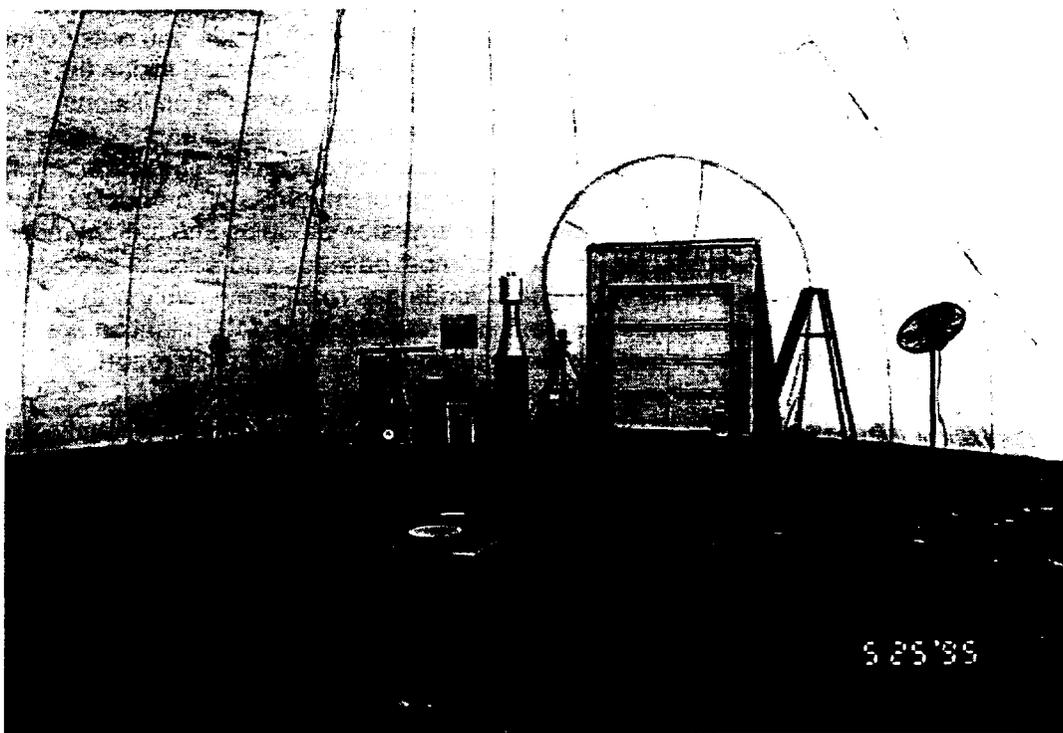


Figure 3-2 The interior of the Air Emissions Test Chamber showing various sampling instruments

3.3 Previous Chamber Studies

The use of the SNL test facility for this particular risk assessment was not without precedent since earlier testing of energetic materials has been completed at this facility for other sponsors. A series of tests were completed in the winter of 1988-89 for the US Army. Successful testing was carried out for an explosive, composite propellant and double base propellant. These earlier tests revealed that both aerosol and gas emission products could be quantitatively collected inside the chamber following a test and that, in general, both unconfined detonation and propellant burning are relatively clean processes that produce virtually undetectable levels of volatile and semi-volatile hydrocarbon emissions that might be of toxicological significance [Einfeld, 1991] Since that initial testing, the facility has been used extensively for explosives and energetic testing and has gone through a number of instrumentation improvements and upgrades.

3.4 Chamber Study Methodology

3.4.1 *Summary Description*

Approximate 1 kg quantities of pure P/E and 4 kg quantities of P/E-contaminated waste were burned inside the test chamber in any particular test. The material was remotely ignited and the combustion process was allowed to go to completion with no operator intervention. The emission products were held in the chamber and were sampled with a range of sampling instruments positioned both inside and outside the chamber. Three large 1-m diameter mixing fans were also positioned inside the chamber to thoroughly mix the contents of the chamber. Samples of emissions products collected were used to determine the total release mass of each of the emission products since the chamber volume is mixed and known. The chamber is relatively leak tight such that only about 20% dilution of the emission products occurs over a two hour interval following release of the emission products into the chamber. Wall and floor effects were typically ignored for most gaseous and aerosol species, however certain species such as hydrogen chloride gas react irreversibly with chamber surfaces so that alternative means of emission factor determination are used. These are described in more detail in a following section of this report.

3.4.2 *Emission Product Measurements*

Specific techniques deployed during the measurement phase are given for gas, aerosol, volatile organic hydrocarbons, semi-volatile hydrocarbons and metals in the following paragraphs.

3.4.2.1 **Gases**

CO₂ - Carbon dioxide was measured using a real-time IR gas filter correlation analyzer. These data were used in the application of the carbon balance method (discussed in more detail below) to calculate emission factors for the a subset of the target pollutants.

CO - Carbon monoxide was measured using a real-time IR gas filter correlation instrument and by evacuated canister and GC analysis. Carbon monoxide was also used in the application of the carbon balance method to these test burns.

NO-NO₂ - Nitrogen oxides were measured using a continuous chemiluminescent analyzer.

HCl - Hydrogen chloride measurements were carried out in the chamber during tests of chlorine-containing composite propellants using open-path fourier transform infrared spectroscopy (Open Path FTIR). The FTIR method affords the best in situ sampling approach that avoids many of the sampling loss problems that occur with extractive sampling methods. A measure of total chlorine consisting primarily of chlorine salts such as ammonium chloride, HCl and Cl₂ was also obtained using a filter/bubbler collection train combined with wet chemical analysis (mercuric ion titration) for total chloride.

NH₃ - Quantitative measurements of ammonia as a potential product of combustion from composite propellants was also available from the FTIR spectrum collected during the tests.

3.4.2.2 Vapors

Total Non-methane Hydrocarbons (TNMHC) - This pollution parameter was determined by evacuated, passivated (SUMMA®) canister sampling methodology coupled with GC methods at the Oregon Graduate Institute of Science and Technology in Portland, OR.

Toxic Volatile Organic Compounds - Analysis of the EPA-designated, 42-compound list of potentially toxic volatile organic compounds was carried out by SUMMA® canister sampling coupled with GC-MS analysis procedures also at the Oregon Graduate Institute of Science and Technology using methodology outlined in EPA Standard Method TO-14.

3.4.2.3 Aerosol

PM₁₀ - Aerosol emissions from all test burns in the chamber were measured with a high volume sampler equipped with a PM₁₀ sampling head. The methodology included gravimetric analysis of the filter collection media.

Size Distribution - Aerosol produced in the burn was sampled and sized in near real-time according to its aerodynamic diameter using an instrument employing laser velocimetry measurement techniques to measure aerodynamic diameter. These data are expected to be useful in estimates of particle fallout and ground deposition under the plume that may be required in follow-on studies

Semi-Volatile Organic Compounds - Semi-volatile organic samples were collected on a modified pesticide sampling unit using pre-fired quartz filters and a XAD-2 resin cartridge. No size differentiation was employed in this sampler, thus total aerosol and associated vapors were collected on the filter and backup resin cartridge. In the laboratory, solvent extraction was used with GC-MS methods to screen for a wide range of potentially toxic semi-volatile species. Target species in the screening analysis included polynuclear aromatic substances such as benzo(a)pyrene, naphthalene, dibenzofuran, phenol, 2,6-dinitrotoluene and as well as other chemical classes. A dioxin screening analysis was also carried out using the same sample extract and similar GC-MS methods.

Heavy Metals - Since many of the propellants to be tested contain heavy metal salts as burn modifiers, an analysis for elements such as Pb, Fe, Bi, Sn, Zr, Mo was also

carried out. A total aerosol sample (no aerosol size selection) was collected on a teflon filter and submitted for x-ray fluorescence analysis at the Lawrence Berkeley Laboratory in Berkeley, CA. This analysis gave a quantitative measure of the mass loading of all of the above noted elements (as well as others) in a single laboratory analysis. An analysis by inductively coupled plasma - atomic absorption spectroscopy was also carried out for selected metals such as aluminum that cannot be done by x-ray fluorescence methods.

3.4.2.4 General Toxicant Screening

In addition to the specific target analytes noted above, limited toxicant screening efforts were carried out on the various sampling media available from the chamber tests. For example, the FT-IR spectra were scanned for the presence of other volatile organic species that might be present in the emissions plume. The TO-14 method to be employed on the evacuated canister samples involved GC-MS screening along with tentative identification of unknown compounds not on the EPA 42-component list that could also be present in the sample. Similar screening was also carried out on the solvent-extracted filters and resin cartridges for semi-volatile organic compounds by GC-MS analysis methods.

3.4.2.5 Pollutant emission factor determination

Target pollutant emission factors were determined by one of two methodologies applied to the data set obtained from the SNL chamber tests. The emission factor is defined here as the total mass yield of a particular pollutant as a fraction of the starting mass of waste material that undergoes burning.

3.4.2.5.1.1 Emission Factor the Volumetric Method

Sampling of pollutants was conducted from a homogeneous mixture inside the chamber. Since the internal volume of the chamber is known, the total mass of a particular pollutant can be estimated for any particular burn scenario. Since the starting mass of waste material is also known the emission factor can be calculated by the following:

$$EF_x = \frac{[X] \cdot V}{M}$$

3.4.2.5.1.2 In this expression, 1

EF_x is emission factor of the pollutant species of interest ($\mu\text{g}/\text{kg}$), $[X]$ is the concentration of species x measured in the chamber following the burn ($\mu\text{g}/\text{m}^3$), V is the volume of the chamber (m^3) and M is the original mass of waste material (kg). In this calculation we assume minimal reactivity of the target pollutants with the interior surfaces of the chamber. While surface effects can never be eliminated, they are judged to be of limited importance since the chamber's internal volume to surface ratio is reasonably large, thus minimizing the interaction of the chamber contents with the chamber walls. A possible exception in this case is the quantitative determination of gaseous chlorine species by virtue of their reactivity with chamber surfaces. In

these cases alternative means of arriving at emission factors are used, as described in following sections of the report.

Emission Factor by the Carbon Balance Method

An alternative approach for the determination of emission factors involves the use of total carbon in both aerosol and gaseous form as a tracer of total waste mass. Provided that the carbon mass fraction of the starting waste material is known, the concentration of any particular pollutant can be ratioed against the total carbon measured in the same volume of air sampled from the chamber. This technique assumes that both aerosol and gases move together as effluents in the plume, experiencing the same mixing and dilution phenomenon. The expression used to determine the emission factor of a particular pollutant is as follows

$$EF_x = F_c \cdot \frac{[X]}{[C_{tot}]}$$

where EF_x is the emission factor of species x , F_c is the carbon fraction of the starting material, $[X]$ is the concentration of the species of interest in the collected sample and $[C_{tot}]$ is the concentration of total carbon in the same sample. The carbon balance method is more versatile than the mass balance approach since a fully-mixed chamber is not required for its application. The carbon balance method compared well with the mass balance technique under a controlled test pollutant emissions from both detonation and burning of energetic materials [Einfeld, 1991].

3.4.3 Chamber Study Test Procedure

The flow of events in a typical test at the Air Emissions Test Chamber is organized chronologically in the abbreviated task list given below.

3.4.3.1 Pre-test Preparations

- Weigh teflon, PS-1 quartz and PM-10 quartz filters under controlled conditions
- Install sampling media in samplers
- Measure initial flow rates on all samplers using a dry gas meter
- Set up video recording equipment to monitor burn progress
- Check calibration on continuous gas monitors
- Weigh out mass of test material

3.4.3.2 Test Procedure

- Place material in burn pan and configure remote ignition apparatus
- Collect background aerosol and gas data prior to test
- Evacuate test chamber and ready for remote ignition
- Inject small amount of SF_6 tracer gas into chamber to track chamber dilution rate
- Start FT-IR spectrometer and continuous gas monitor data acquisition systems

Remotely ignite test material and observe burn via video camera

Allow combustion products to mix inside the chamber for 5 minutes following burn completion

At $T_0 + 5$ minutes remotely start samplers and operate for 60 - 120 minutes

Continuously monitor gas concentrations and aerosol size distributions for 60 minutes following burn

At $T_0 + 10$ minutes collect evacuated canister sample

3.4.3.3 Post-Test Procedure

Re-enter chamber and measure flow on all samplers

Following flow measurements, retrieve all sampling media

Weigh residual ash material, if present, in burn pan

Download gas monitoring data from data logger to computer data file

Post-process FT-IR spectral data files

3.4.4 Post-Test Sample Analysis

A variety of analyses were carried out on the various samples collected during each test burn. A brief description of the various procedures for each of the chamber interior sampling systems follows.

3.4.4.1 Teflon Filter

For the pure energetic burns, the Teflon filter was submitted for X-ray fluorescence analysis at Lawrence Berkeley Laboratory. The filter was screened for those elements known to be in the original energetic material. Results were reported in mass loading (ng of element per square centimeter of filter area). The product of the element mass loading and the filter area gave a total mass collected.

3.4.4.2 Mixed Cellulose Ester Filter

This filter was used to collect an aerosol sample for aluminum determination since aluminum is not done well by X-ray fluorescence. The alternative procedure involved acid digestion of the filter followed by ICP-AAS analysis. The analysis was performed at the SNL Environmental Chemistry Laboratory.

3.4.4.3 Nylon Filter

This filter was used to collect a total nitrate sample during the pure propellant burns since the nylon filter media is an efficient collector of both gaseous nitrate (nitric acid) and aerosol nitrate species.

3.4.4.4 Low-flow Bubbler System

The bubbler system incorporated a 37 mm diameter mixed cellulose ester filter in a plastic cassette followed by two midget glass impingers connected in series and filled

with 0.1 N sulfuric acid. The sampler was designed to collect both aerosol and gaseous chloride species such as ammonium chloride and hydrogen chloride during composite propellant burns. Analysis was done by water extraction of the filter and mercuric chloride titration of the filter extract and the two bubbler solutions.

3.4.4.5 PS-1 Sampler Filter and Resin

The PS-1 sampler used a 10 cm diameter quartz filter followed by a 25 gram section of pre-cleaned XAD-2 resin. The quartz filter was pre- and post-test weighed to determine total aerosol weight gain. Following weighing the filter and companion resin cartridge were shipped to an analytical chemistry laboratory and the Battelle-Pacific Northwest Laboratory where they were Soxhlet extracted over a period of 24-hours using a methylene chloride solvent. The solvent was evaporated and ultimately blown down to a total volume of 1 ml from which aliquots were taken for injection into GC-FID and GC-MS-Ion Trap systems. The GC-FID system was used for target list compound quantitation by peak retention time and the GC-MS-Ion Trap system was used for compound confirmation.

3.4.4.6 PM-10 Quartz Filter

The 8x10-inch filter from the PM-10 sampler was pre- and post-test weighed along with control filters in order to derive an estimate of PM-10 mass released during each combustion test. No additional analysis was carried out on this filter.

3.4.5 Building Volume Determination

On selected tests, a known volume of pure SF₆ gas was released into the chamber immediately prior to the burn test. The concentration of the tracer gas was then continuously monitored by an open-path FT-IR. The mass concentration of tracer gas was determined from the spectral data and used to derive the total volume of the chamber. Repeated tracer gas measurements yielded a chamber volume of 784 m³ with an uncertainty of about 2%.

3.4.6 General Data Processing Procedures and Calculations

Each sample analysis yielded a measure of the total mass of a particular species on the collection medium. Information on the flow rate of each sampler was also collected before and after each sample collection interval. The product of the flow rate average (calculated from the initial and final sampler flow rate) and the sampling interval gave a measure of the total volume of air sampled. Calculation of the emission factor for each pollutant type was carried out in the following manner: The total mass of a particular species measured in the sample was divided by the total air volume sampled to yield a measure of the mass concentration in the chamber. A correction factor was introduced to account for the limited amount of chamber air dilution that occurred over the one or two hour sampling interval. Typically, this correction factor was on the order of +10 to +20 percent and was determined by measuring the rate of dilution of the inert tracer gas injected into the chamber during the test from the FT-IR spectral data. This corrected concentration value was then multiplied by the internal air volume of the building to arrive at an estimate of total mass of a particular pollutant that was released during the test. The ratio of this

estimate of total mass release to the starting mass of test material gives the emission factor for that particular species.

A slightly different procedure was used for the continuous gas data to account for chamber dilution effects. Earlier testing has shown that exponential decay laws accurately describe the dilution characteristics of the chamber. Exponential decay theory reveals that a plot of the log of the concentration of a particular species with elapsed time yields a linear plot with the intercept at time zero being equal to the virtual mixed concentration of the gas at the completion of the burn. In reality, the contents of the chamber are not fully mixed for about five minutes following burn completion, however tracking gas data continuously over a 1-hour interval allows extrapolation of the data back to an actual total mass release at burn completion. In this manner a zero-time concentration of the various criteria pollutant gases such as carbon monoxide, nitrogen dioxide and sulfur dioxide was determined. The product of this derived zero-time gas concentration and the building volume yielded a good estimate of the total mass release of each gas following the test burn. Emission factors were determined as described in the previous paragraph by ratioing the total mass release of each gas to the starting mass of the test material.

3.4.7 Chamber Test Matrix

A list of waste materials tested along with other descriptors such as number of tests and test dates is given in Table 3-2. A further breakdown of the two PE contaminated waste mixtures with respect to composition is given in Table 3-3.

Table 3-2 SNL Air Emissions Test Matrix

Material Description	No. of Tests	Approx. Burn Mass kg	Test Dates
Background Chamber Sample	1	N/A	25-May-95
Al-Composite Propellant	2	0.4	30-May95 31-May-95
Composite Propellant	2	0.4	01-Jun-95
Double Base Propellant	2	0.4	07-Jun-95
PBX Explosive	2	0.4	08-Jun-95
P/E-contaminated Waste - Mix 1 [Double Base + Acetone + Sawdust]	1	3.6	27-Jul-95
P/E-contaminated Waste - Mix 2 [PBX, Composite + Acetone + Sawdust + Misc. Wood and Plastics]	1	3.2	02-Aug-95

Table 3-3 Mass breakdown of P/E-contaminated waste mixtures burned in the test chamber

Constituent	Mass, g
Mix No. 1	
Double Base Propellant	400
Acetone	800
Sawdust	2,800
Mix No. 2	
PBX	100
Composite Propellant	100
Acetone	200
Gasoline	200
Sawdust	800
Miscellaneous Waste - Cellulosic	607
Miscellaneous Waste - Plastics	721



4. CHEMICAL HAZARD IDENTIFICATION RESULTS

4.1 Target Analyte List

A target analyte list of both gaseous and aerosol combustion products was included in the project work plan that was submitted to the State of West Virginia, Office of Air Quality for review and approval. The list includes a variety of potentially toxic gas and aerosol species likely to be encountered during energetic materials combustion and has been informally adopted by many state agencies and consultants as a logical starting point in the risk assessment process. Much of the list is based on work done by SNL and others as part of a technical steering committee for the US Army during the initial study in which chamber testing methods were introduced as a means of estimation of pollutant emission factors for materials slated for disposal by open burning and detonation methods [AMCCOM, 1992].

The initial target analyte list is given in Tables 4-1, 4-2, 4-3 and 4-4 as taken from a proposed work plan for a risk assessment to be conducted at Beale Air Force Base, CA [Mullins, 1995] and is broken down into chemical sub-categories. A second column in the table gives a yes or no indication as to whether the particular species was measured during SNL testing of the ABL waste categories.

Table 4-1 Target Analyte Gases

Species	Measured in SNL Testing Program?
Carbon Monoxide	yes
Sulfur Dioxide	yes
Nitrogen Dioxide	yes
Hydrogen Chloride	yes
Hydrogen Cyanide	yes
Ammonia	yes

Table 4-2 Target Analyte Non-Carcinogenic Volatile and Semi-Volatile Organic Compounds

Species	Measured in SNL Testing Program?
biphenyl	yes
di-n-propyladipate	yes
diethylenetriamine	yes
1,6-dinitropyrene	yes
2,6-dinitrotoluene	yes
dioctyl sebacate	yes
diphenylamine	yes?
2,5-diphenyloxazole	yes?
5-ethyl-1,3-diglycidyl-5-methylhydantoin diepoxide	no (See Note 2)
isophorone di-isocyanate	no (See Note 3)
2,2-methylenebis(4-methyl)-6-t-butylphenol	no (See Note 3)
1-methylnaphthalene	yes
2-methylnaphthalene	yes
naphthalene	yes
2-nitrophenylamine	yes
4-nitrophenylamine	yes
nitroglycerin	no (See Note 2)
2-nitronaphthalene	yes
4-nitrophenol	yes
1-nitropyrene	yes
phenanthrene	yes
phenol	yes
phenyldi-isodecyl phosphite	no (See Note 3)
pyrene	yes
resorcinol	yes
salicylic acid	no (See Note 2)
triacetine	yes
1,1,3-trimethyl-3-phenyllindane	no (See Note 3)
1,3,5 trinitrobenzene	yes

Table 4-3 Target Analyte Carcinogenic Metals, Volatile and Semi-Volatile Organic Compounds

Species	Measured in SNL Testing Program?
arsenic	no (See Note 1)
cadmium	no (See Note 1)
chromium (VI)	no (See Note 1)
nickel	yes
benz(a)anthracene	yes
benzene	yes
benzo(a)pyrene	yes
dibenz(a,h)anthracene	yes
dibenzofuran	yes
2,4-dinitrotoluene	yes
2-naphthylamine	yes
N-nitrosodiphenylamine	yes
4-nitrosodiphenylamine	yes

Table 4-4 Target Analyte Non-Carcinogenic Heavy Metals

Target Species	Measured in SNL Testing Program?
aluminum	yes
antimony	no (See Note 1)
arsenic	no (See Note 1)
barium	no (See Note 1)
cadmium	no (See Note 1)
chromium	no (See Note 1)
copper	yes
iron	yes
lead	yes
nickel	yes

Table Notes:

Note 1: The element was not expected as an emission since it is not contained in any of the material raw ingredients.

Note 2: The compound is thermally labile and not suited for conventional GC-MS analysis. Alternative methods for determination were outside the scope of work on this project.

Note 3: The component is not an ingredient in the original mixture of materials, nor is it likely to be produced during combustion. As a cost containment measure, analysis was not carried out.

4.2 Chamber Study Emission Factors

4.2.1 *Pure Energetics*

Target analyte emission factors for the pure energetic materials tested in the SNL chamber are given for gases and vapors in Tables 4-5 and Table 4-6 for semi-volatile organic and heavy metal aerosols. The emission factor given is the highest of two measurements made on each material. Emission factors were calculated by the chamber volume method as described in Section 3.4.2.5 for all species except volatile organic compounds collected in the evacuated canister, selected elemental species and hydrogen chloride. The carbon balance technique, also described in Section 3.4.2.5 was used for the volatile organics in the canister samples. For selected heavy metals, as noted in the Table 4-6, the mass fraction of the element in the original material was used as a conservative estimate of the emission factor. Here the assumption is made that the element is completely aerosolized and injected into the plume. This approach avoids the problems with arriving at an emission factor from the chamber measurements since these measurements are complicated by the fact that some gravitational settling of the aerosol occurs over the sampling interval used in the chamber during the tests. We have chosen in this screening analysis to assume worst-case conditions—which are, no aerosol settling loss from either the puff or plume.

We used a similar assumption for arriving at an emission factor for HCl during composite propellant combustion. Hydrogen chloride gas was measured in the chamber by the FT-IR spectrometer during testing however, we could account for only 30-40% of the total chlorine in the original material by both FT-IR and bubbler sampling techniques. The reason for this is the fact that HCl is extremely reactive and is known to irreversibly absorb to the chamber walls and floor. To get around this problem, we conservatively assume that all chlorine present in the original mix is released as hydrogen chloride. This is an appropriate approach in the screening analysis and may very well be the best approach for all evaluations since much of the literature published on emission products from composite fuel combustion suggests that hydrogen chloride is the final end product for all chlorine-containing intermediate species that may exist in the flame zone during combustion of the material [Urbanski, 1964].

Table 4-5 Gas and Volatile Organic Compound Emission Factors for Pure Energetics

Chemical Species	Emission Factor (g/kg)			
	Al-Composite Propellant	Composite Propellant	Double Base Propellant	PBX Explosive
CO	< 2.0E-1	1.2E-1	3.0E+0	2.9E-1
NO	3.6E+0	4.0E+0	2.3E+0	2.4E+0
NO2	5.9E-1	5.9E-1	1.9E-1	3.1E-1
SO2	4.0E-1	1.0E-1	4.1E-2	1.4E+0
HCl	2.2E+2	2.6E+2	NA	NA
NH3	<5.7E-1	<1.6E-2	<5.7E-1	<5.7E-1
n-Hexane	<1.6E-2	<2.2E-2	<4.5E-3	<3.1E-3
1,3 Butadiene	<1.6E-2	<2.2E-2	<4.5E-3	<3.1E-3
Benzene	1.1E+0	1.5E-1	2.1E-2	<3.1E-3
Toluene	1.6E-2	1.1E-1	<5.3E-3	<3.1E-3
Styrene	<1.6E-2	<2.2E-2	<5.3E-3	<3.1E-3
Xylenes (o,m,p)	<1.6E-2	8.6E-2	<5.3E-3	6.2E-3

Notes:

NA = not applicable. The species was either not measured or not expected to be present as an emission product.

HCl emission factors are estimated from the mass fraction of chlorine in the energetic material (see text).

A "<" preceding a number indicates that the species was not detected at the indicated detection level.

Table 4-6 Semi-Volatile Organic and Aerosol Emission Factors for Pure Energetic Materials

Chemical Species	Emission Factor (g/kg)			
	Al-Composite Propellant	Composite Propellant	Double Base Propellant	PBX Explosive
PM-10	5.7E+1	4.8E+0	1.1E+1	5.3E+0
Aluminum	1.0E+2	NA	NA	NA
Lead	NA	NA	8.8E+0	NA
Zirconium	NA	8.8E+0	8.8E+0	NA
Copper	NA	NA	NA	4.0E+1
Molybdenum	NA	NA	NA	NA
Iron	NA	NA	NA	1.1E-2
Mesitylene	3.3E-5	5.9E-5	8.4E-5	3.0E-4
Phenol	<2.8E-3	2.8E-3	2.3E-4	6.2E-4
Naphthalene	1.1E-3	3.9E-3	7.1E-5	2.5E-4
Thianaphthene	<9.0E-5	<8.5E-5	<5.4E-5	2.9E-4
Resorcinol	5.5E-3	2.3E-3	6.0E-3	1.2E-3
2-Methylnaphthalene	8.6E-3	9.3E-3	5.9E-3	<6.5E-3
1-Methylnaphthalene	2.4E-3	9.0E-4	1.2E-4	<4.8E-4
Tracetin	<9.0E-5	<8.5E-5	<5.4E-5	<4.9E-5
Biphenyl	4.7E-3	1.0E-3	1.9E-4	1.3E-3
2,6-Dinitrotoluene	7.2E-6	5.8E-3	4.7E-3	5.4E-3
Dibenzofuran	1.0E-3	6.9E-4	1.7E-4	1.4E-4
4-Nitrophenol	<9.0E-5	<8.5E-5	<5.4E-5	<4.9E-5
2,4-Dinitrotoluene	<9.0E-5	5.8E-3	<5.4E-5	<4.9E-5
Di-n-propyl adipate	<2.7E-3	<2.7E-3	<9.5E-4	9.0E-4
Diphenylamine	1.9E-4	<1.9E-4	<1.4E-4	1.4E-4
2-Nitronaphthalene	<5.4E-4	1.7E-3	2.3E-4	3.8E-4
Phenanthrene	2.0E-3	2.9E-4	3.5E-4	1.1E-4
2,5-Diphenyloxazole	9.5E-4	4.3E-7	1.7E-4	2.5E-4
N-Nitrosodiphenylamine	<9.0E-5	<8.5E-5	<5.4E-5	<4.9E-5
Pyrene	<9.0E-5	<8.5E-5	<5.4E-5	<4.9E-5
4-Nitrosodiphenylamine	<9.0E-5	<8.5E-5	<5.4E-5	<4.9E-5
Benz[a]anthracene	<9.0E-5	4.4E-3	3.3E-3	<3.3E-3
1-Nitropyrene	<4.4E-3	<8.5E-5	<5.4E-5	<<4.9E-5
Benzo[a]pyrene	<9.0E-5	<8.5E-5	<5.4E-5	<4.9E-5
1,6-Dinitropyrene	<9.0E-5	<8.5E-5	<5.4E-5	<4.9E-5
Dibenz[a,h]anthracene	<9.0E-5	<8.5E-5	<5.4E-5	<4.9E-5
Dioxin	<6.5E-4	<6.5E-4	<4.9E-4	<4.9E-4

4.2.2 P/E-contaminated Mixtures

Emission factors for the P/E-contaminated mixtures are given in Tables 4-7 and 4-8. Some gases such as CO, NO and SO₂ were released in much greater quantities than observed for the pure energetics. Higher levels of these gaseous species originated from the smoldering combustion of sawdust, wood and other cellulosic products. Non-detectable levels for many of the volatile hydrocarbons were observed however for Mix No. 1. A high acetone background raised the GC-MS detection levels appreciably so that higher non-detectable levels are reported when they are compared to the results for Mix No. 2.

Table 4-7 Gas and Volatile Organic Compound Emission Factors for P/E-contaminated Waste

Target Species	Emission Factor (g/kg)	
	Mix No. 1 Double Base/ Sawdust/Acetone	Mix No. 2 PBX/Composite/Sawdust/ Acetone/Misc. Waste
CO	4.0E-1	3.5E+2
NO	2.4E+0	2.0E+0
NO2	9.2E-1	1.1E+0
SO2	1.7E-1	7.6E-1
HCl	NA	1.1E+1
NH3	<6.4E-2	<1.2E-1
n-Hexane	<3.3E-1	<4.8E-4
1,3 Butadiene	<3.3E-1	<4.8E-4
Benzene	<3.3E-1	<4.8E-4
Toluene	<3.3E-1	3.5E+0
Styrene	<3.3E-1	<4.8E-4
Xylenes	<3.3E-1	9.4E-1

Note:

The HCl emission factor is derived from the total chlorine content in the composite propellant which is a component of the P/E-contaminated mixture

Table 4-8 Semi-Volatile Organic and Aerosol Emission Factors for P/E-contaminated Waste

Target Species	Emission Factor (g/kg)	
	Mix No. 1 Double Base/ Acetone/Sawdust	Mix No. 2 PBX/Composite Acetone/Sawdust Misc.Waste
PM-10	5.1E+0	7.4E-3
Aluminum	NA	NA
Lead	NA	NA
Zirconium	NA	NA
Copper	NA	NA
Molybdenum	NA	NA
Iron	NA	NA
Mesitylene	<1.1E-5	<1.8E-5
Phenol	<1.1E-5	<1.8E-5
Naphthalene	<1.1E-5	<1.8E-5
Thianaphthene	<1.1E-5	<1.8E-5
Resorcinol	<1.1E-5	<1.8E-5
2-Methylnaphthalene	<1.1E-5	<1.8E-5
1-Methylnaphthalene	<1.1E-5	<1.8E-5
Tracetin	<1.1E-5	<1.8E-5
Biphenyl	<1.1E-5	<1.8E-5
2,6-Dinitrotoluene	<1.1E-5	<1.8E-5
Dibenzofuran	<1.1E-5	<1.8E-5
4-Nitrophenol	<1.1E-5	<1.8E-5
2,4-Dinitrotoluene	<1.1E-5	<1.8E-5
Di-n-propyl adipate	<1.1E-5	<1.8E-5
Diphenylamine	<1.1E-5	<1.8E-5
2-Nitronaphthalene	<1.1E-5	<1.8E-5
Phenanthrene	<1.1E-5	<1.8E-5
2,5-Diphenyloxazole	<1.1E-5	<1.8E-5
N-Nitrosodiphenylamine	<1.1E-5	<1.8E-5
Pyrene	<1.1E-5	<1.8E-5
4-Nitrosodiphenylamine	<1.1E-5	<1.8E-5
Benz[a]anthracene	<1.1E-5	<1.8E-5
1-Nitropyrene	<1.1E-5	<1.8E-5
Benzo[a]pyrene	<1.1E-5	<1.8E-5
1,6-Dinitropyrene	<1.1E-5	<1.8E-5
Dibenz[a,h]anthracene	<1.1E-5	<1.8E-5
Dioxin	<5.5E-5	1.0E-4

5. DOSE-RESPONSE ASSESSMENT

The primary focus of any health risk assessment is an evaluation of the potential toxicological impact on a selected population following exposure to a particular chemical species that may be released to the general atmosphere. To conduct a quantitative risk assessment, estimates of the degree of adverse health response of an exposed individual as a function of chemical dose are required for both carcinogenic and non-carcinogenic chemical species. The quantification of dose-response relationships is an important component of the field of experimental toxicology since the results of experimental tests on various animal systems are used to extrapolate dose-response effects to human exposure conditions. These data on dose-response effects for a wide range of chemicals have been collected from the scientific literature, interpreted by review panels and compiled into a number of EPA-maintained databases to facilitate their use in quantitative risk assessments such as described here.

5.1 Overview of Dose-Response Criteria Derivation

Although a detailed discussion of the derivation of risk based concentrations and the accompanying rationale for their determination is beyond the scope of this report, a few general comments concerning the methodology used in the assessment of exposure effects are in order. Specifically, brief comments are made on carcinogenic and non-carcinogenic substances and how quantitative estimates of acceptable exposure are made.

5.1.1 *Carcinogenic Species*

The dose-response data for a particular species are compiled from the literature and collectively evaluated with regard to such issues as the animal system used in the study, route of exposure, duration of exposure, degree of confidence in the data along with numerous other issues. From these data, a carcinogenicity slope factor is estimated with some built-in conservatism from a health effects standpoint. The slope factor is a quantitative estimate of the cancer risk to be expected per milligram of the species per kilogram of exposed individual body weight per day of continuous exposure over a lifetime (70-year) period. For ambient air exposures, these cancer slope factors can also be expressed as a risk based concentration (RBC) which, in simple terms, is a 24-hour average concentration level which would result in a target cancer risk of one in a million (10^{-6}) to any individual exposed over a lifetime. Numerous adjustment factors and qualifications enter into the determination of these RBC values by review panels and are beyond the scope of this report.

5.1.2 *Non-Carcinogenic Species*

A slightly different approach is taken for the estimation of acceptable exposure levels for non-carcinogenic species. In general, the animal and human exposure data in the literature is compiled and used to derive what is called a no observable adverse effect level (NOAEL). Assessments are made as to the animal system tested, the

degree of confidence in the data and so on, in arriving at the no effect level. This NOAEL concentration then functions much like the RBC described in the previous paragraph. A hazard quotient is used to express non-cancer exposure risks to a population. The hazard quotient is the result of dividing the expected exposure level for a particular chemical by the "no effect" exposure level. Hazard quotients in excess of 1 are suggestive of unacceptable exposure levels whereas hazard quotients less than unity are indicative of acceptable population exposure levels in the sense that continuous exposure at these levels would not be expected to cause adverse health effects in an exposed human population

5.2 Chronic Exposure Criteria

In this study we have used a tabulation of risk assessment exposure criteria published by the toxicology staff of EPA Region 3. [Smith, 1995]. This tabulation in turn draws upon a number of toxicological databases, developed and maintained by various entities within the US EPA, in which risk based concentrations or no effect exposure levels are developed from experimental data in the scientific literature. Toxicological constants given in the EPA Region 3 tables are derived from the following databases in order of priority: (1) IRIS; (2) HEAST; (3) HEAST-Alternative Method; (4) EPA Superfund Health Risk Technical Support Center; (5) IRIS or HEAST- species withdrawn from the database; and, (6) Other EPA sources³. We also gained access to IRIS2 which a PC-based database version of IRIS which is under development for selected government users only. Queries of IRIS2 were used to confirm those given in the EPA-Region 3 tables for selected species of interest. Table 5-1 gives the risk based concentration or the no observable effect exposure level for those entries on the target analyte list for which experimental data is available and on which consensus a degree of consensus has been reached by EPA review panels.

For criteria pollutants such as PM-10, CO, SO₂, Lead and others, the National Ambient Air Quality Standards (NAAQS) were used as a measure of acceptable exposure levels

A review of the toxicological databases for safe exposure levels reveals entries of "no entry" or "data under review" for many of the target analytes selected in this study. In such cases, we make no attempt to estimate reasonable exposure levels, since such an exercise places a high emphasis on professional judgment and should be left to review panels made up of trained toxicologists.

³ HEAST is an acronym for Health Effects Assessment Summary Tables; IRIS is an acronym for Integrated Risk Information Systems; STSC is an acronym for the EPA Superfund Technical Support Center

Table 5-1 RBC and NOAEL Concentrations for Target Analytes

Target Species	RBC or NOAEL ug/m ³	Source
nitrogen dioxide	100	NAAQS
carbon monoxide	10,300	NAAQS
sulfur dioxide	365	NAAQS
pm-10	150	NAAQS
hcl	7.3	IRIS
aluminum	3,700	STSC
lead	1.5	NAAQS
zirconium	N/A	
copper	N/A	
molybdenum	N/A	
n-hexane	210	IRIS
benzene	0.22	IRIS
xylenes	310	HEAST
mesitylene	1.5	STSC
phenol	2,200	IRIS
naphthalene	N/A	
thianaphthene	N/A	
resorcinol	N/A	
2-methylnaphthalene	N/A	
1-methylnaphthalene	N/A	
tracetine	N/A	
biphenyl	180	IRIS
2,6-dinitrotoluene	3.7	HEAST
dibenzofuran	15	STSC
4-nitrophenol	230	Other EPA
2,4-dinitrotoluene	7.3	IRIS
di-n-propyl adipate	N/A	
diphenylamine	91	IRIS
2-nitronaphthalene	N/A	
phenanthrene	N/A	
2,5-diphenyloxazole	N/A	
N-nitrosodiphenylamine	N/A	
pyrene	110	IRIS
4-nitrosodiphenylamine	N/A	
benz[a]anthracene	0.01	STSC
1-nitropyrene	N/A	
benzo[a]pyrene	0.001	IRIS
1,6-dinitropyrene	N/A	
dibenz[a,h]anthracene	0.001	ECAO
dioxin	5E-8	IRIS

5.3 Acute Exposure Criteria

The exposure criteria noted above are intended for application in circumstances where population exposure persists over long time intervals, for example, over a 70-year lifetime, and are intended for the prevention of chronic adverse health effects. For the majority of chemical species encountered, the chronic exposure scenario is the major concern. For selected chemicals however, short term or acute adverse health effects are also important. The release of hydrogen chloride from the combustion of composite type rocket fuels containing ammonium perchlorate is an example of an acute or short term exposure hazard that also requires evaluation.

Hydrogen chloride is an irritant gas which affects respiratory passageways and can produce considerable discomfort to exposed individuals. Short-term exposure to gases such as these must be kept below concentration thresholds at which these irritant effects become manifest. A number of acute exposure criteria are available for assessment of injury potential following short-term exposure to hydrogen chloride vapor. These are briefly summarized below:

5.3.1 AIHA Emergency Response Planning Guidelines

For acute exposure evaluation, one set of exposure criteria known as Emergency Response Planning Guidelines (ERPG) are often used. These guidelines have been compiled by the American Industrial Hygiene Association (AIHA) through a consensus process among professionals [AIHA, 1992]. Three levels of ERPG's, namely the ERPG-1, ERPG-2 and ERPG-3, are published for a variety of chemical species that can produce adverse health effects following acute exposure. The three levels are based on the degree to which adverse health effects are willing to be tolerated for a short-term exposure with the ERPG-1 being the most conservative from a health protection standpoint. A description of the ERPG-1 is given in the following paragraph.

The ERPG-1 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor [AIHA, 1992]

The ERPG-2 and 3 categories are less stringent, offering a lower degree of protection during a typical 1-hour exposure. The ERPG guidelines for HCl are as follows:

ERPG-1 Maximum concentration of 3 ppmv HCl not to be exceeded over the duration of one hour.

ERPG-2 Maximum concentration of 20 ppmv HCl not to be exceeded over the duration of one hour.

ERPG-3 Maximum concentration of 100 ppmv HCl not to be exceeded over the duration of one hour.

Since the ERPG-1 category is the most conservative exposure guideline, it is most appropriate of the three for use in this acute exposure health risk assessment.

The ERPG-2 and 3 categories are less stringent, offering a lower degree of protection during a typical 1-hour exposure. Since the ERPG-1 is the most conservative exposure guideline, we deem it the most appropriate of the three for use in this acute exposure screening assessment. The ERPG-1 for HCl is 3 ppmv for a 1-hour concentration level. Other HCl exposure criteria include the ACGIH Threshold Limit Value and Occupational Safety and Health Administration Permissible Exposure Level which are both set at a 5 ppmv ceiling value not to be exceeded at any time during exposure. It is important to note that the Threshold Limit Values and Permissible Exposure Levels are specifically intended for application in workroom environments and in a general sense, should not be used to evaluate non-worker population exposure scenarios. Another EPA screening criteria for acute exposure hazards has been to use one-tenth of the Immediately Dangerous to Life and Health (IDLH) value established by the National Institute of Safety and Health (NIOSH). The IDLH value for HCl is 100 ppmv and the corresponding screening level would be 10

ppmv. This is an instantaneous HCl concentration value above which exposures should not occur for any period of time. It is apparent from this brief discussion that a range of exposure standards are available for application in this particular exposure assessment. Additional discussion of this matter will be presented in the segment of the report that discusses risk characterization results (Section 7).

5.3.2 EPA Screening Level

The National Institutes for Occupational Safety and Health (NIOSH) lists an Immediately Dangerous to Life and Health (IDLH) concentration level which the EPA uses as a guideline in establishment of the EPA screening level. Normally, 10% is the IDLH is used as the screening level. Thus the HCl EPA screening level would be 10 ppmv.

5.3.3 Occupational Exposure Guidelines

Current occupational HCl exposure guidelines are set at a 5 ppmv ceiling value which should not be exceeded at any time. These exposure standards are intended for occupational use only and are generally not suitable for exposure assessment of the general population.

5.3.4 US Air Force Space Command Exposure Guidelines

The US Air Force has established a three-tier exposure system for use in evaluating HCl exposure to the general public who may be exposed to exhaust plumes from aborted rocket launches. Tier 1, which is the most conservative and appropriate for this assessment, specifies a 1-hour time weighted average not to exceed 2 ppmv with a ceiling value of 10 ppmv.

6. EXPOSURE ASSESSMENT

6.1 Approach

Exposure assessment in this air pathways risk assessment was carried out in a three-step process. An initial screening evaluation was followed by additional in-depth analysis of specific burn scenarios targeted for specific pollutants. Limited on-site plume characterization was also carried out. Further information on each of these sub-tasks is given in the following paragraphs

6.1.1 Screening Analysis

During the initial phase of the project, a screening exposure assessment was done for three distinct burn scenarios by using estimated propellant burn rates, estimated plume temperatures, and measured target analyte emission factors as source term inputs for several dispersion model evaluations. Worst-case meteorology was used in three screening model runs to determine the highest 1-hour exposure concentration likely to be observed for the range of species on the target analyte list anywhere within a pre-established receptor field. Two additional runs were completed using on-site meteorological data collected over a one-year interval at the ABL burning ground. Complex terrain was also taken into account in the modeling evaluation. Additional details on the various aspects of the screening analysis are given in Appendix A.

6.1.2 Final Analysis

Results from the screening analysis were combined with data from a number of on-site measurements of energetic material burning dynamics that were taken during burning operations, and further used to formulate a second set of propellant burn scenarios that were judged to be more representative of actual plume release and dispersal conditions at the site. The final modeling analysis concentrated on those chemicals which were suggested to pose unacceptable or marginal risk on the basis of the screening analysis. Exposure assessment through dispersion modeling at the existing burning ground was augmented with additional analysis at a proposed alternate burning ground site located in the east central region of the plant property.

6.1.3 On-Site Analysis

Limited on-site plume impact assessment at on-plant and off-plant receptor sites was carried out during a one-week sampling period in November 1995. Several combustion scenarios were monitored with air sampling equipment designed to collect selected plume species. Additional details concerning this effort are given at the conclusion of this section.

6.2 Source Term Data

6.2.1 Screening Analysis

Measurements of plume temperature and burn rate were incorporated as one task in the project however these data were not available when the initial screening analyses were carried out. Estimates of propellant burn rates and temperature derived from other work were used in the initial screening analyses. The burning conditions encountered at the site were categorized into low, medium and high burning rate and plume temperatures were conservatively estimated at the low end since higher temperatures would produce more plume loft and diminished plume impacts on the local surrounding terrain.

For each modeled event, the maximum allowable daily burn pan limit, discussed earlier in Section 2.3.3.3.2, was used in the source term calculations. Emission factors for the target analytes measured in the SNL chamber experiments were used along with the total burn mass and burn rate to estimate the mass release rate of the various target analytes selected for evaluation in the study. Plume release characteristics such as plume diameter, plume vertical velocity, plume temperature and the initial puff size in the high burn rate case, were estimated using observed conditions during actual burning ground operations as well as using test data from the SNL burn tests at the SWISH facility.

Five burn scenarios at the existing burning ground were evaluated in the screening analyses as summarized below:

Case 1 - High Burn Rate Puff Release with Screening Meteorology

Case 2 - Intermediate Burn Rate Continuous Release with Screening Meteorology

Case 3 - Low Burn Rate Continuous Release with Screening Meteorology

Case 4 - Intermediate Burn Rate Continuous Release with On-site Meteorology

Case 5 - Low Burn Rate Continuous Release with On-site Meteorology

Additional detail on model inputs and assumptions for the screening analyses are given in Appendix A.

6.2.2 Final Analysis

The results from the screening analyses were used to develop an additional set of propellant burning and plume dispersion scenarios for selected target pollutants. Screening analyses results indicated that Pb and HCl were of primary interest in terms of potential health impacts to the surrounding community. Many of the assumptions used in the screening analyses were determined to be overly conservative and not representative of actual burning conditions at the plant. Plume temperature and propellant burn rate data were available from on-site measurements conducted in November 1995 for incorporation into model inputs. These data are described more fully in the model inputs section.

For the screening and final analyses, the point of origin of the puff or plume was assumed to be the center of the burning ground. Although the burning ground actually contains five functional burning pads, their consideration as a single source

in this analysis does not produce any significant difference compared to treating the five sources independently.

6.3 Dispersion Models

A puff model was used to model the high burn rate cases and a continuous release plume dispersion model was used to evaluate the medium and low burn rate conditions. A brief description of each of these models follows.

6.3.1 TRPUF Model

We used a gaussian puff model called TRPUF which was developed by Trinity Consultants for short term pollutant releases that are best described by a single puff. TRPUF is a gaussian puff model that is adapted from the EPA puff model and includes several enhancements the basic algorithms contained in the EPA PUFF model. Other features of the model are more fully described below.

Downwind Concentrations

TRPUF calculates downwind concentrations at each receptor for three distinct stability classes and reports results for all classes at a series of downwind distances ranging from 10 to 11,000 meters along with the maximum value encountered under any of the three general stability classes. The stability classes are unstable (Classes A, B and C), neutral (Class D) and stable (Classes E and F). Dispersion coefficients for each of the stability classes are user selected and for these runs the Pasquill-Gifford tabulations were selected.

Initial Puff Description

The initial puff size can be described by specifying the initial puff size in horizontal and vertical one-sigma distances along with the downwind distance at which the puff is observed or by specifying the release amount and initial concentration of a particular pollutant in the puff.

Plume Rise

Three plume rise formulations are included in the TRPUF model however when no building down wash conditions are specified, as was in case in our modeling runs, only two of these are used to evaluate plume rise. One is Brigg's momentum plume rise and the other is Brigg's distance dependent buoyant plume rise. The first assumes that the plume goes to its highest point immediately above the release point and the second allows the plume to make a gradual ascent to its maximum height. The type of plume rise is dependent upon the stability class so that different rise algorithms may be used under different stability classes.

Building Downwash

The model includes provisions for the inclusion of building structures in the vicinity of the plume, however we do not discuss them in any detail here since the modeled release scenarios do not include structures in the immediate vicinity of the release point.

Model Output

Output data are available in both tabular and graphical format and both are used in the results presented in this report. In general we relied upon tabular data since

these could easily be read for a number of downwind distances ranging from 10 to 11,000 meters from the release point.

Topography

Although the model is not specifically designed deal with complex terrain, the user does have the option of setting the receptor height at some level other the burn pan elevation. We used this capability to evaluate maximum 1-hour average concentrations at a range of receptor heights corresponding to the range of altitudes encountered in the region surrounding ABL. Additional details on this approach are given in the paragraphs dealing with model setup parameters and discussion of results.

6.3.2 **ATDM/ISCST3 Model**

At the start of the project, we used the All Terrain Dispersion Model (ATDM), a gaussian plume dispersion model developed by the EPA and commonly used for regulatory compliance analysis. The user interface for this EPA-sanctioned model is developed by Trinity Consultants, Dallas, TX. This model was used to evaluate continuous plume releases in the medium and slow burn rate cases in the screening analyses. The ATDM model is a hybrid gaussian dispersion model that calculates concentrations from point, area, and volume source emissions in *simple* (receptor at or below stack height), *intermediate* (receptor above stack height and below stabilized plume center-line) and *complex* (receptor above stabilized plume center-line) terrain. The ATDM model uses plume dispersion algorithms contained in two EPA dispersion models, namely, ISCST2 and COMPLEX1. It also uses the algorithm in the POSTIT post-processor to calculate concentrations in intermediate terrain.

Later in the project, the ATDM model was replaced by a new release of the Industrial Source Complex (ISC) model from which ATDM is derived. The new version, ISCST3 or ISC3, incorporates all of the features of ATDM model with improvements in ease-of-use and various algorithms. The ISC3 model was used for final dispersion analyses. Further references to the ISC3 model in this report equally apply to the ATDM model used earlier in the project since the two models are essentially the same in terms of plume dispersion algorithms and data output.

Terrain Designations

For receptors located in simple terrain, the ISC3 and ATDM models use the ISC algorithms to calculate downwind receptor site concentrations. Aerosol gravitational settling and deposition are disabled in this particular configuration however to provide a worst case evaluation. Receptors located in complex terrain are handled by the COMPLEX1 algorithm which incorporates various means to account for changes in plume height as the plume passes over topographical features. How the plume height is influenced by local terrain is determined by the meteorological stability class and the height of the plume above each receptor point for which a calculation is carried out. In the case of receptors falling in intermediate terrain, the ISC3 model calculates receptor concentrations using both algorithms and selects the highest result for output.

Sources

The models can handle multiple sources, however, in this screening analysis, we have chosen to model the burning operations as a single point source. Additional

details on receptor field designation, complex terrain input, and meteorological inputs are given in following sections. A complete description algorithms in the ATDM and ISC3 models can be found in the EPA users guide for the ISC model [EPA, 1992].

Output

Output data from the models are available in both tabular and graphical format and both are used in the results presented in this report. Graphical data were directly imported into a graphical software package such that concentration isopleths of the plume at the receptor field can be prepared.

Topography

As is evident from earlier discussions on terrain, the model accepts a receptor field in three-dimensional space so that topographical features can be taken into account in the plume dispersion calculations.

Building Effects

Like the TRPUF model, the ATDM and ISC3 models have the capability of dealing with wind wake effects from large structures in the vicinity of the source however, this capability was not necessary in these analyses since no large structures are encountered close enough to the burning ground to exert any wind flow pattern influence.

Meteorology

The models will accept a variety of meteorological inputs ranging from a EPA-designated screening meteorological data set to on-site hourly meteorological data. In the screening and final assessments both options were used. The screening file contains a series of atmospheric stability categories and wind speeds that would be bracket meteorological conditions likely to be encountered at the site. The on-site data consist of hourly observations of wind speed and direction, temperature, stability class, and mixing height.

6.3.3 Topography Data

We downloaded topographical data for the United States Geological Survey CUMBERLAND map (No. 39078-A1) via the Internet from a USGS web site at the Earth Science Information Center at Reston, VA. These map data are 1:250,000 scale derived from a Digital Elevation Model and are packaged in 1 degree latitude by 2 degree longitude blocks for the entire continental US as well as Hawaii and Alaska. The basic digital elevation model is produced by the US Defense Mapping Agency using cartographic and photographic data sets. The horizontal resolution of these data are 3 arc-second or approximately 70 meters in longitude (at 39.5N degrees latitude which corresponds to the ABL location) and about 90 meters in latitude. Elevation data from the digital elevation model are given to the nearest meter. These data were first converted from latitude-longitude (WGS-1984 coordinate system) to UTM coordinates since the ISC3 and ATDM models are best suited for UTM coordinates. The data were then passed to SURFER®, which is a 3-D graphics data package, where additional interpolation was done to produce an appropriate grid density for use in the dispersion model. The surface and topographical maps shown in Figures 2-4 and 2-5 were produced from the USGS topographical data in this manner.

6.3.4 Receptor Field Designation

Eighteen radials were constructed starting at the center of the burning ground and projecting outward, starting at true north and progressing around the compass at 20 degree intervals. A receptor point was selected every 150 meters along each of the radials for a total of 33 receptor points along each radial. These 18 radials were input into the 3-D graphics package along with the elevation grid obtained from the USGS. The altitude from the grid was then determined at each receptor point by cross comparison of these two data sets using algorithms in the software. From these analyses, a receptor field was set up in polar coordinates with the grid center located at the center of the burning ground. The polar grid had a overall diameter of 9.9 km and contained 594 individual receptor points, each with a designated altitude to the nearest meter. These data were then passed to the ISC3 model and used as the receptor field for the various modeled scenarios.

6.3.5 Meteorological Data

Three types of meteorological data were used in the modeling runs described in this section: (1) worst-case meteorology for puff dispersion; (2) worst-case meteorology for continuous plume dispersion; and (3) on-site meteorological data collected near the ABL burning ground over a period of one-year with various meteorological instruments. The first two are further discussed in following sections that describe model inputs. A brief discussion of the on-site meteorological data follows:

On-site meteorological data was collected at the ABL burning ground during the period December 1994 through November 1995. In late November 1994, an acoustic sounder was set up at the burning ground in order to develop winds speed and direction profiles in 15-minute intervals to assist in establishing burn criteria. In late February 1995, a 30-m meteorological tower was installed at the burning ground that included a full suite of meteorological sensors such as wind speed, wind direction, temperature, relative humidity, and solar intensity and other parameters. Data from these two systems were combined by Aerovironment Inc., under contract to the ABL facility, to produce a one-year meteorological data set at the 30-m level, for use the ATDM air dispersion model. The data set included hourly averages of wind direction, wind speed, temperature, stability class (determined from multi-level temperature, and/or solar insolation measurements, and/or sodar data), and mixing height. Quality assurance procedures were carried out on these data sets by Aerovironment personnel prior to their release to Sandia for inclusion in modeling runs. Additional information on these data processing and quality assurance efforts is contained in a separate report currently in publication by Aerovironment.

6.4 Model Inputs for Puff and Plume Release Scenarios

Source term release scenarios for the final exposure assessment analysis are summarized in Table 6-1 and further described in the following paragraphs. Source release scenarios for the preliminary screening analysis are given in Appendix A.

Table 6-1 Revised ABL Burn Scenarios

Case	Site	Propellant	Source Mass Kg	Burn Rate g/s	Plume Temp °C	Model	Meteorology
A1 A2	Existing	Al-HTPB	182	3,000 800	1800	TRPUF	Site Subset
B	Existing	Double Base	182	200	1800	ISC3	Site Subset
C1 C2	Alternate	Al-HTPB	182	3,000 800	1800	TRPUF	EPA Subset
D	Alternate	Double Base	182	200	1800	ISC3	EPA Subset

Note:

Existing burning ground coordinates: UTM Zone 17, 686050 m Easting, 4381780 m Northing, 213 m MSL

Alternate burning ground coordinates: UTM Zone 17, 685008 m Easting, 4380457 m Northing, 260 m MSL

6.4.1 Case A1 - Aluminized HTPB - High Burn Rate - Existing Site

The TRPUF model was used for evaluation of probable peak instantaneous and time-weighted average HCl exposures in areas adjacent to the burn site using input data that was modified following the screening analyses and ensuing discussions between Sandia, ABL and WV Office of Air Quality. Model setup and input parameters that were used for this case are given in Table 6-2.

Input data changes from the original screening analysis included an increase in plume temperature based on thermocouple measurements made at ABL in November 1995; a change in the total propellant mass per burn to a maximum of 182 kg, to be consistent with the current consent order; and, a change in the original puff diameter from 50 m to 15 m to account for the reduced propellant burn mass.

Table 6-2 TRPUF Input Data for Cases A1 and C1

Model	TRPUF—Gaussian Puff Model (Trinity Consultants, Dallas, TX)
Propellant	Aluminized HTPB Composite
Target Pollutant	Hydrogen Chloride
Burn Mass	182 kg
Chlorine Mass Fraction	0.217 (ABL Report Table 2-2, p 12)
HCl Mass Fraction	0.22
HCl Release Mass	40 kg
Burn Rate	3,000 g/s
Burn Duration	61 s
Ambient Air Temperature	20 C
Plume Release Height	1 m
Plume Velocity	5 m/s
Plume Temperature	1,000 C ⁴
Initial Puff Diameter	15 m
Initial Puff Volume	1,770 m ³
Initial Puff HCl Concentration	14,900 ppmv
Wind Speed	1.5 m/s
Dispersion Coefficients	Pasquill-Gifford
Receptor Heights	0, 10, 25, 50, 100, and 200 m above burn pit elevation
Meteorological Criteria	Evaluations for all wind directions at 20 deg increments. Stable meteorological conditions allowed. ⁵

⁴ Plume temperature measurements conducted in November 1995 indicate plume temperatures in excess of 1800 C. The model however is limited to a maximum temperature of 1,000 C.

⁵ The model evaluates downwind plume impacts for three general stability categories: unstable, neutral, and stable. The maximum value at each downwind distance was selected from all three stability categories.

6.4.2 Case A2 - - Aluminized HTPB - Moderate Burn Rate - Existing Site

A modification of the burn rate from 3,000 g/s to 800 g/s, the burn interval, a corresponding change in the initial puff diameter from 15 m to 50 m, and a change in the initial puff HCl concentration from 14,940 ppmv to 403 ppmv (as a result of the increased initial puff size) are the changes made between Case A1 and Case A2. Model input parameters for Case A2 are given in Table 6-3.

Table 6-3 TRPUF Input Data for Cases A2 and C2

Model	TRPUF—Gaussian Puff Model (Trinity Consultants, Dallas, TX)
Propellant	Aluminized HTPB Composite
Target Pollutant	Hydrogen Chloride
Burn Mass	182 kg
Chlorine Mass Fraction	0.217 (ABL Report Table 2-2, p 12)
HCl Mass Fraction	0.22
HCl Release Mass	40 kg
Burn Rate	800 g/s
Burn Duration	228 s (3.8 min)
Ambient Air Temperature	20 C
Plume Release Height	1 m
Plume Velocity	5 m/s
Plume Temperature	1,000 C ⁶
Initial Puff Diameter	50 m
Initial Puff Volume	65,450 m ³
Initial Puff HCl Concentration	403 ppmv
Wind Speed	1.5 m/s
Dispersion Coefficients	Pasquill-Gifford
Receptor Heights	0, 10, 25, 50, 100, and 200 m above burn pit elevation
Meteorological Criteria	Evaluations only for wind directions greater than 260° and less than 120° Stable meteorological conditions allowed. ⁷

⁶ Plume temperature measurements conducted in November 1995 indicate plume temperatures in excess of 1800 C. The model however is limited to a maximum temperature of 1000 C.

⁷ The model evaluates downwind plume impacts for three general stability categories: unstable, neutral, and stable. The maximum value at each downwind distance was selected from all three stability categories.

6.4.3 Case B - Double Base - Moderate Burn Rate -Existing Site

The screening evaluations of double base burns at a moderate burn rate were carried out using the ATDM model from Trinity Consultants. A final exposure analysis was carried out with the ISC3 model in order to incorporate estimated annual average Pb concentrations since these were not computed in the screening analysis. Model input data for Case B are given in Table 6-4. The only significant changes in model inputs were a limitation of the propellant burn mass to 182 kg per hour, to be consistent with the current consent order under which disposal operations are conducted, and, an increase in the plume temperature to 1800 °C.

The polar receptor grid was also expanded to a radius of nearly 5 km from the center of the existing burning ground. In addition, a set of discrete receptor points corresponding to the ABL property line were included in the model's receptor field. Figure 6-1 is a diagram of the polar coordinate and plant boundary receptor grid for the Case B analysis.

Table 6-4 Case B Model Inputs

Model	ISC3 (Trinity Consultants, Dallas, TX)
Source	Double Base Propellant
Burn Mass	182 Kg
Pb Mass Fraction	0.009
Pb Release Mass	1.6 Kg
Burn Rate	200 g/s
Pb Emission Rate	1.8 g/s
Burn Duration	15 min
Ambient Air Temperature	20 °C
Plume Diameter	5 m
Plume Velocity	5 m/s
Plume Temperature	1800 °C
Dispersion Coefficients	Pasquill-Gifford
Dispersion Mode	Rural
Receptor Height	1.7 m agl
Meteorological Data	On-site meteorological data set Evaluation only between 9AM and 4PM

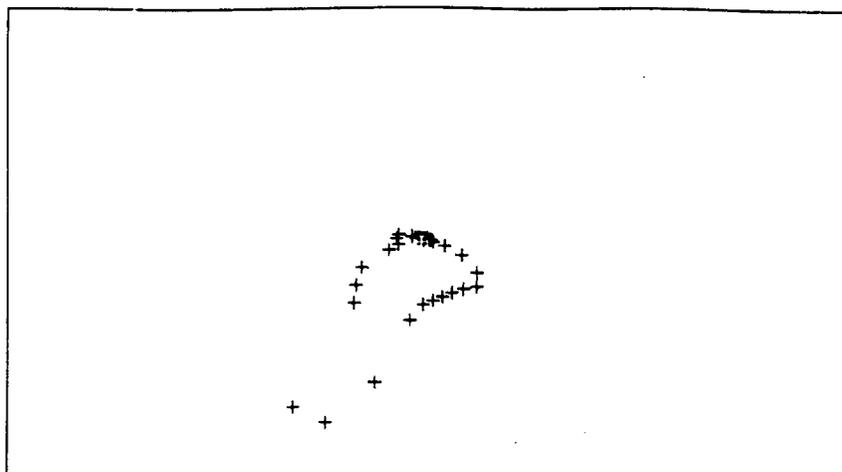


Figure 6-1 Diagram of the Case B receptor field. A receptor point is marked by the intersection of each radial line and circle. The crosses are also receptor points corresponding to the approximate ABL plant boundary line. The burning ground is at the center of the circle.

6.4.4 Case C1 - Aluminized HTPB - High Burn Rate - Proposed Alternate Site

A similar puff model evaluation was carried out for a potential alternate burn site with the same burn configuration and rates used for Case A1. The alternate burn site is located on ABL property about 0.5 km southwest of the junction of the ABL main entrance road and State Route 956. Site coordinates are UTM Zone 17, 4380458 m Northing, 685008 m Easting, 260 m MSL elevation. Model inputs are as shown in Table 6-2. The only change made was in the source location. For the alternate burn site, plume impacts with local terrain were evaluated for all wind directions (in 20 degree increments starting at 0 degrees).

6.4.5 Case C2 - Aluminized HTPB - Moderate Burn Rate - Proposed Alternate Site

The change from Case C1 to C2 is identical to the change from Case A1 to A2 described previously. The burn rate drops to 800 g/s and the initial puff diameter increases considerably, causing a lower initial HCl concentration in the puff. As noted previously for Case A2, the net result is an approximate 15% drop in peak and average HCl concentration values. Thus the high value of 12 ppmv would drop to about 10 ppmv with the accompanying 2-minute average dropping from 7.7 to 6.5 ppmv. Model inputs for Case C2 are shown in Table 6-2.

6.4.6 Case D - Double Base - Moderate Burn Rate - Proposed Alternate Site

With one exception, input data for Case D were the same as for Case B, given previously in Table 6-4. The on-site meteorological data, collected near the existing burn site, was supplemented with screening meteorological data in a second model run. The screening file contains a range of 29 wind speed and atmospheric stability combinations which encompass the range of meteorological conditions likely to be

encountered at this site. In accordance with a previous agreement between ABL and the WV Office of Air Quality, the F stability class was dropped from the screening file since this stability is normally encountered only in the evening and early morning hours when no burning would be conducted at the site. Wind directions were incremented by 20 degrees in the screening met file, thus 18 sets of screening criteria (one set of 29 conditions at a wind direction of 0 degrees, a second at a wind direction of 20 degrees, and so on) were evaluated in the model run. These meteorological screening data were used to estimate maximum hourly Pb concentrations in the terrain surrounding the alternate burn site. A diagram of the receptor field also showing the ABL boundary receptors and the alternate burn site is shown in Figure 6-2.

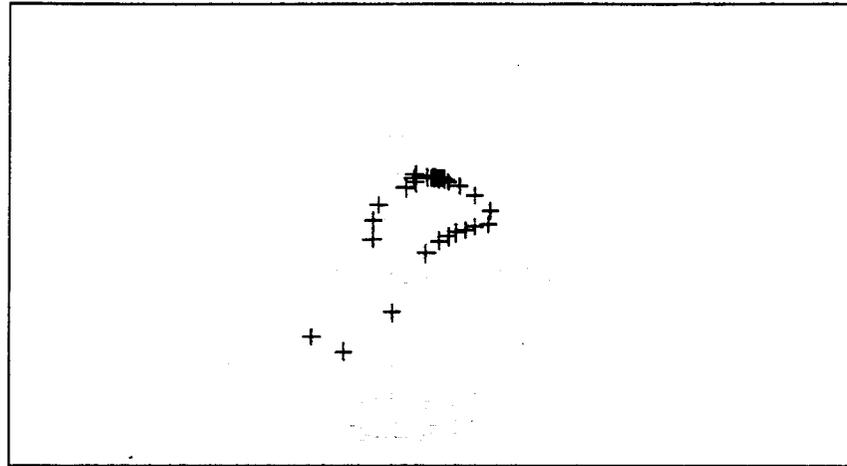


Figure 6-2 Diagram of the Case D receptor field

6.5 Modeling Results

Model results are given in the following paragraphs for five burn scenarios associated with the final exposure assessment. Results for the various screening assessments conducted earlier in the project are included in Appendix A.

6.5.1 Case A1

The model was run six times, once for each of the receptor heights shown in Table 6-2. A default wind speed value of 1.5 m/s was used in all model runs. This relatively low wind speed yields conservative results (high concentrations), in keeping with the overall approach taken in this health risk assessment. Model outputs were obtained for maximum instantaneous and 1-hour average HCl concentrations as a function of downwind distance. A plot of maximum instantaneous HCl concentrations at the six receptor heights is shown in Figure 6-3. Terrain elevations along a radial from the center of the burning ground out to a distance of 5 km were then overlaid onto the HCl plot as shown in Figure 6-4. A total of 18 radials, at 20-degree increments was used to represent the local terrain. The region of plume impact and the associated maximum instantaneous HCl concentrations for each of the six receptor heights was manually read from each plot. These are compiled in Table 6-5 for all of the 18 radials evaluated. Under the Consent Order Open Burning Management Plan, open burning is conducted only if the wind direction is greater than 260° and less than

120° (radials between 80° and 300°). Data for other radials is shown for comparison purposes only.

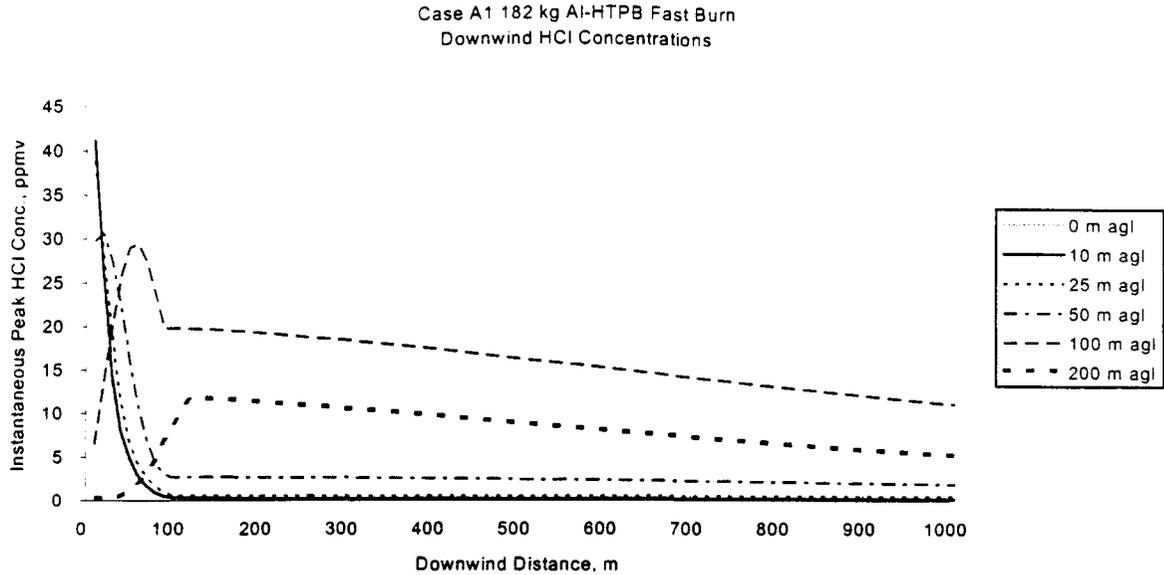


Figure 6-3 Case A1: Maximum instantaneous HCl concentrations with downwind distance.

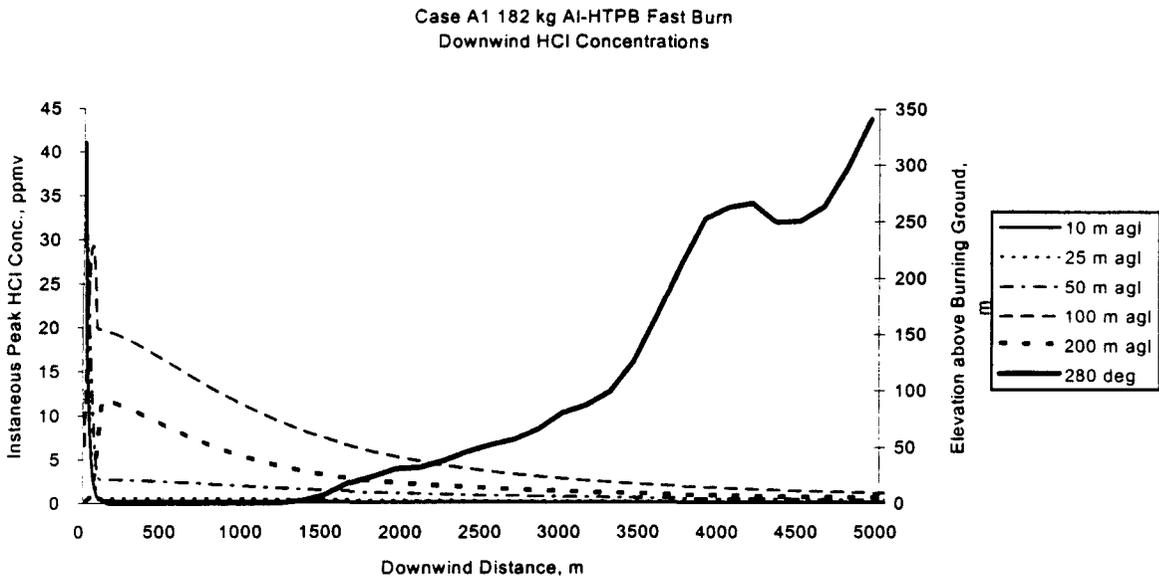


Figure 6-4 Example plot of maximum HCl concentrations and terrain elevation as a function of distance from the burn site along the 280 degree radial.

Table 6-5 Case A1: Peak Instantaneous HCl Concentrations

Radial (deg)	Wind Dir (deg)	Peak instantaneous HCl concentration (ppmv) at indicated receptor height					
		0 m	10 m	25 m	50 m	100 m	200 m
0	180	<1	<1	<1	1.0	NT	NT
20	200	<1	<1	<1	1.7	NT	NT
40	220	<1	<1	<1	<1	2.0	<1
60	240	<1	<1	<1	1.3	4.2	1.5
80	260	<1	<1	<1	1.2	4.8	1.8
100	280	<1	<1	<1	1.3	5.8	2.2
120	300	<1	<1	<1	3.7	7.5 ³	2.7
140	320	<1	<1	<1	1.8	6.0	NT
160	340	<1	<1	<1	1.9	8.7 ²	2.3
180	360	<1	<1	<1	2.0	9.5 ¹	1.7
200	20	<1	<1	<1	2.2	2.7	1.4
220	40	<1	<1	<1	1.5	NT	NT
240	60	<1	<1	<1	<1	<1	NT
260	80	<1	<1	<1	1.2	1.8	NT
280	100	<1	<1	<1	1.2	2.5	1.2
300	120	<1	<1	<1	1.0	3.0	1.2
320	140	<1	<1	<1	1.0	2.7	1.0
340	160	<1	<1	<1	1.0	1.8	<1

NT = No plume impact with terrain within 5 km of burn site. Impacts that may occur beyond the 5 km limit are below levels of concern.

¹ Highest occurrence at a point approximately 1,000 m downwind from the burn site along the 180 degree radial.

² Second highest occurrence at a point approximately 1,250 m downwind from the burn site along the 160 degree radial.

³ Third highest occurrence at a point approximately 1,500 m downwind from the burn site along the 120 degree radial.

Additional model runs were carried out for the three highest impact regions given in Table 6-5. Acute human exposure potential was evaluated as a 2 minute and 1-hour time weighted average, assuming the passage of a single puff over the receptor site per averaging interval. These model output data are summarized in Table 6-6. The principal impacted area lies to the southwest of the existing burning ground along the plant boundary line as shown in Figure 6-5. The plume impact occurs in a region that is undeveloped at this time; however, the impacted region is adjacent to State Route 956 which transects the ABL facility and Knobly Mountain.

Table 6-6 Case A1: Highest three peak instantaneous and average HCl concentrations.

Impact Region Severity Level	HCl Concentration, ppmv		
	Peak Instantaneous	2-min average	1-hour average
Highest Conc.	9.5	7	0.2
2 nd Highest Conc.	8.7	6	0.2
3 rd Highest Conc.	7.5	5	0.2



Figure 6-5 Topographical Map of the ABL vicinity showing the region of maximum HCl plume impact for Case A1. The impacted region is shown crosshatched. The ABL plant boundary is shown as a heavy line.

6.5.2 Case A2

Plume-impacted regions for Case A2, the moderate burn rate case, are the same as encountered in Case A1. Peak instantaneous and corresponding 2-minute and 1-hour HCl concentration levels are about 15% lower than those values shown in Tables 6-5 and 6-6. Thus, the highest HCl peak level of 9.5 ppmv for Case A1 becomes 8.0 ppmv for Case A2 and the corresponding 2-minute average goes from 7 ppmv to 6 ppmv.

6.5.3 Case C1

Model output consists of maximum instantaneous and 1-hour average HCl concentrations as a function of downwind distance. The regions of plume impact and the associated maximum instantaneous HCl concentration on the surrounding terrain for each of the six receptor heights are given in Table 6-7. The highest levels are recorded for a sector between the 100 and 160 degree radials, approximately 1,000 m downwind, as shown in Figure 6-6. The impacted region is along the southwest ABL plant boundary line where it runs adjacent to State Route 956 along the top of the ridge line. The impacted region is undeveloped at this time; however moderate traffic volume is encountered on Route 956.

As discussed previously for Case A1, additional model runs were carried out for the three highest impact regions noted in the previous tables. Acute human exposure potential was further evaluated as 2-minute time weighted averages, assuming the passage of a single puff over the receptor site per averaging interval. These data are summarized in Table 6-8. Two-minute average HCl concentrations fall in the vicinity of 7 ppmv and the 1-hour average concentrations are about 0.2 ppmv for the three highest plume impacts.

Table 6-7 Peak HCl Concentrations for Case C1: High Rate Al/Composite Burn at Alternate Site

Radial (deg)	Wind Direction (deg)	Peak instantaneous HCl concentration (ppmv) at indicated receptor height					
		0 m	10 m	25 m	50 m	100 m	200 m
0	180	<1	<1	NT	NT	NT	NT
20	200	NT	NT	NT	NT	NT	NT
40	220	NT	NT	NT	NT	NT	NT
60	240	<1	<1	<1	<1	2.3	1.5
80	260	<1	<1	<1	2.3	3.7	1.7
100	280	<1	<1	<1	2.3	12.0 ¹	NT
120	300	<1	<1	<1	2.4	12.0 ²	2.5
140	320	<1	<1	<1	2.3	10.5 ³	2.2
160	340	<1	<1	<1	1.8	8.8	2.2
180	0	<1	<1	<1	1.5	5.8	1.8
200	20	<1	<1	<1	2.0	7.5	1.5
220	40	NT	NT	NT	NT	NT	NT
240	60	NT	NT	NT	NT	NT	NT
260	80	<1	<1	<1	<1	NT	NT
280	100	<1	<1	<1	1.0	2.3	1.4
300	120	<1	<1	<1	1.0	2.7	1.0
320	140	<1	<1	<1	1.0	3.0	1.3
340	160	<1	<1	<1	<1	2.0	NT

NT = No plume impact with terrain within 5 km of burn site. Impacts that may occur beyond the 5 km limit are below levels of concern.

¹ Highest occurrence at a point approximately 1,000 m downwind from the burn site along the 100 degree radial.

² Second highest occurrence at a point approximately 1,000 m downwind from the burn site along the 120 degree radial.

³ Third highest occurrence at a point approximately 1,000 m downwind from the burn site along the 140 degree radial.

Table 6-8 Case C1 Peak and Time Weighted Average HCl Concentrations for the High Three Occurrences

Impact Region Severity Level	HCl Concentration, ppmv		
	Peak Instantaneous	2-min average	1-hour average
Highest Conc.	12.0	7.7	0.2
2 nd Highest Conc.	12.0	7.7	0.2
3 rd Highest Conc.	10.5	7.0	0.2



Figure 6-6 Topographical Map of the ABL vicinity showing the region of maximum HCl plume impact for Case C1. The impacted region is shown crosshatched. The ABL plant boundary is shown as a heavy line.

6.5.4 Case C2

The change from Case C1 to C2 is identical to the change from Case A1 to A2 described previously. The burn rate drops to 800 g/s and the initial puff diameter increases considerably, causing a lower initial HCl concentration in the puff. As noted previously for Case A2, the net result is an approximate 15% drop in peak and average HCl concentration values. Thus the high value of 12 ppmv would drop to about 10 ppmv with the accompanying 2-minute average dropping from 7.7 to 6.5 ppmv.

6.5.5 Case B

Model outputs included the three highest 1-hour Pb concentrations, assuming that the source was continuous for the entire hour. The actual burn time of the propellant is 15 minutes however. The hourly averages were adjusted by a factor of 0.47 which was derived by assuming an exponential decay of the Pb emission rate in the remaining 45 minutes following cessation of the 15-minute burn. The three highest hourly values and their accompanying locations are shown in Table 6-9. A plot of the location of maximum 1-hour concentrations relative to the ABL boundaries is given in Figure 6-7.

An annual average computation was also carried out during the model run using the on-site meteorology. In this computation a continuous double base propellant source with Pb emissions is assumed to be burning from 9AM to 4PM every day of the week. The annual average concentration for each receptor site is tabulated by the model. The three highest values are also given in Table 6-9. The 0.47 correction factor noted above was combined with an additional correction factor of 0.71 to account for the fact that burns typically occur on a maximum of five days per week.

Table 6-9 Case B: Existing Site/Double Base Modeling Results

Type of Occurrence	Site Location UTM Easting / Northing / Elev (m)	Pb Concentration, ug/m ³
Highest 1-hour average	687293 / 4380787 / 396	17.6
2 nd high 1-hour average	687479 / 4380955 / 356	11.0
3 rd high 1-hour average	687207 / 4380401 / 312	5.8
Highest annual average [†]	686050 / 4381630 / 213	0.021
2 nd high annual average	686050 / 4381480 / 213	0.016
3 rd high annual average	688118 / 4381416 / 413	0.011

[†] The computed annual averages are **conservative** values since the assumption is made that a burn occurs every hour between 9AM and 4PM every week day of the year. Anticipated burn mass, based on plant production, would result in considerably less (<10%) of the assumed burn activity in this model run.

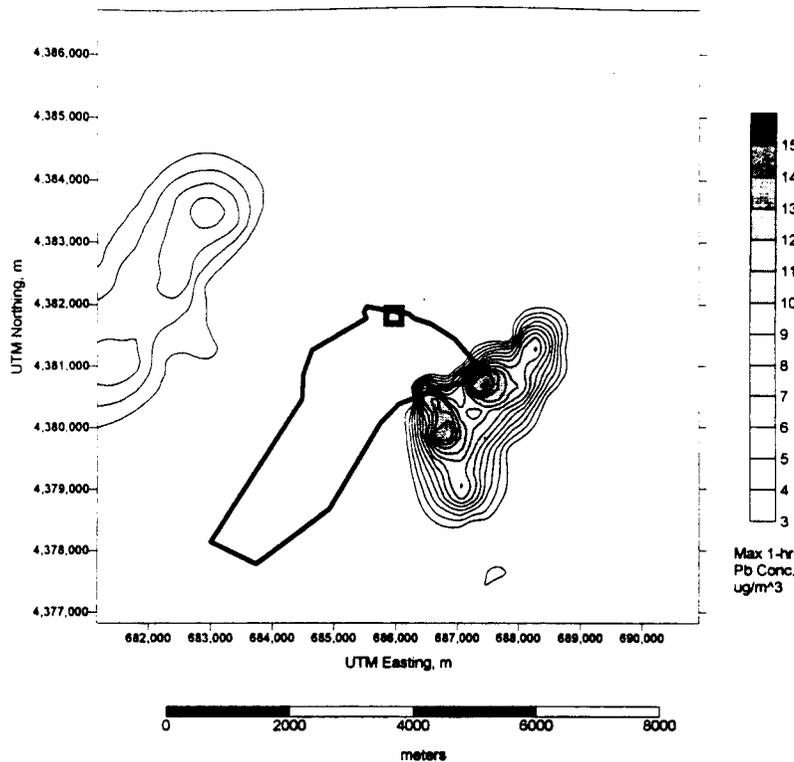


Figure 6-7 Case B model results showing Pb peak concentration isopleths for the highest occurrence. The burning ground is marked with a rectangle and the ABL plant boundary is shown by the heavy black line.

The most important data in Table 6-9 are the annual averages since Pb is evaluated as a chronic toxin in this assessment. The two highest annual averages shown in the table occur inside the plant boundaries at locations very near the burn site itself. The third highest site is encountered about 2 km east of the burn site on the high ridges overlooking the ABL complex. These annual averages are conservative (high) numbers since the assumption is made that burning is done every hour from 9AM to 4PM every week day (1820 hours/year). The total estimated mass of lead-containing propellant expected to be burned is about 14,000 kg per year. At 182 kg per burn, approximately 75 burns or 75 hours per year would be required to consume this mass. Thus, based on expected burn activity, annual average Pb concentrations would be expected to be less than 10% of those values given in Table 9. Further discussion of these results in the context of risk characterization will be given following the presentation of Case D results.

6.5.6 Case D

Output from the model included the three highest 1-hour Pb concentrations, assuming that the source was continuous for the entire hour. As noted for Case B, the actual burn time of the propellant is 15 minutes however. Consequently, the hourly averages were adjusted by the same factor of 0.47 used for Case B. The three highest hourly values computed using the screening meteorological data file are given along with corresponding locations in Table 6-10.

A maximum 1-hour and annual average Pb concentration computation was also done using the meteorology collected at the existing ABL burn site and used in the Case B evaluation. These data are given in Table 6-10. Correction factors of 0.47 and 0.71 were used, as in Case B, to account for a burn interval less than 1 hour and no weekend burning.

As noted previously in the discussion of results from Case B, the most important data in Table 6-10 are the annual averages since Pb is evaluated as a chronic toxin. The maximum 1-hour averages give an indication of the locations of plume impact however they are not particularly useful for estimation of annual average concentrations since the hourly meteorology varies significantly throughout the year. In this case, the annual averages were determined using the on-site meteorological data set from the existing burn site which is approximately 1.5 km distant from the alternate site. Although this meteorological data set was not collected at the alternate site, it is from the general ABL vicinity and clearly more superior to a meteorological data set from a "nearby" National Weather Service site such as Morgantown. For this analysis, the meteorology at the alternate site is assumed to be comparable to that encountered in the existing burn site. Elevation and terrain differences between the two sites will contribute to local meteorological differences at each site however. All three annual averages shown in Table 6-10 occur inside the plant boundaries at locations southwest of and very near the alternate burn site. As discussed previously in the Case B evaluation, the annual averages are conservative (high) numbers since the assumption is made that burning is done once each hour between 9AM to 4PM every day (1820 hours/year). The actual maximum annual burn time, based on expected plant production and accompanying waste, would be about 10% of the modeled burning time. Further discussion of these results with respect to risk characterization will be given in the following report section.

Table 6-10 Case D Alternate Site/Double Base Modeling Results

Type of Occurrence	Site Location UTM Easting / Northing / Elev. (m)	Pb Concentration, ug/m ³
Highest 1-hour average Screening Met	685790 / 4380065 / 412	26.2
2 nd high 1-hour average Screening Met	685790 / 4380065 / 412	26.2
3 rd high 1-hour average Screening Met	685790 / 4380065 / 412	26.2
Highest 1-hour average On-site Met	685148 / 4380526 / 263	10.8
2 nd high 1-hour average On-site Met	685148 / 4380526 / 263	9.6
3 rd high 1-hour average On-site Met	685148 / 4380526 / 263	9.0
Highest annual average ¹ On-site Met	685148 / 4380526 / 263	0.026
2 nd high annual average On-site Met	685148 / 4380474 / 262	0.023
3 rd high annual average On-Site Met	685790 / 4380065 / 412	0.017

Note that the computed annual averages are **conservative** values since it was assumed that a burn occurs every hour between 9AM and 4PM every week of the year. Anticipated burn mass, based on plant production, would result in considerably less (about 5%) of the assumed burn activity in this model run.

6.6 On-Site Plume Sampling

6.6.1 Sampling and Analysis Methodology

Plume sampling was conducted by SNL and ABL personnel during the week of November 13-17, 1995 at the ABL facility. Two PS-1 samplers, identical to the those used in the chamber tests, were used to collect ground-level air samples at selected locations near the burning ground during typical burning operations. Nominal air sampling flow rates of both samplers was 125 ambient liters per minute. A total of 8 samples were collected over 4 days of testing. Sampling duration ranged from 20 to 1000 minutes as dictated by the type and duration of burning activity being monitored. Testing on the second day of the week was suspended as a result of heavy snowfall in the area and Department of Defense restrictions against burning operations during periods of high winds.

The sampling media consisted of a 10 cm diameter high-purity quartz filter followed by a resin cartridge containing 50 g and 20g of pre-cleaned silica gel in two sections separated by a polyurethane foam plug. The sampling media was intended to collect Pb aerosol and total Cl, both in aerosol and gaseous form. The silica gel was pre-extracted and dried with deionized water in order to reduce background Cl levels on the media.

Samplers were operated continuously during burning operations and were positioned downwind of the active burn pan, to the extent possible. Real-time meteorological data from the on-site 30 m tower was used to estimate the downwind plume path and predict optimum locations for sampler positioning. On selected days, the samplers were positioned across the river to the north and northeast of the burning ground, in the vicinity of residential dwellings potentially impacted by burning ground operations.

Analysis of the sampling media was carried out at the Industrial Hygiene Chemistry Lab at Sandia National Laboratories. The quartz filters underwent aqueous extraction for Cl anion and were subsequently leached with concentrated nitric acid for Pb extraction. All silica gel and foam separators were similarly extracted with aqueous solution. Chloride anion analysis on all extracts was done by mercuric nitrate titration. Lead analysis was done by flame atomic absorption spectrometry.

6.6.2 Sampling and Analysis Results

A summary of sampling activities is given in Table 6-11, showing the sample date, number, location, duration and associated burn activity.

Table 6-11 On-site Plume Sampling Summary Description

Sample Date	Sample No./Description	Location UTM-x/UTM-y	Sample Duration min	Burn Activity
11/13/95	1/Admin Bldg	685406/4381005	1006	Dble Base - 181 kg
11/13/95	2/RR Track	685556/4381619	897	
11/15/96	3/X-Range	687329/438092	344	Dble Base - 181 kg
11/15/95	4/Gate 28	N/D	338	
11/16/95	5/Frankenberry	686419/4381609	373	Compsite- 152 kg Dble Base - 130 kg
11/16/95	6/Twigg	686330/4381683	343	
11/17/95	7/Frankenberry	686419/4381609	137	Dble Base - 130 kg
11/17/95	8/Twigg	686330/4381683	122	
11/15/95	9/Blank	N/A	N/A	N/A
11/15/95	10/Blank	N/A	N/A	N/A

Analysis of all on-site air samples produced non-detectable levels of Cl and Pb in all relevant sampling media. These non-detectable levels were carried through a calculation using the total sampler air volume to determine an equivalent detection-limit air concentration for Cl and Pb and are summarized in Table 6-12. Further discussion of the resulting exposure health risk for these data is given in the following section of this report.

Table 6-12 Summary On-Site Air Sampling Results

Sample No.	Sample Air Vol. m ³	Cl-total ug	Cl Air Conc. ug/m ³	Pb-filter ug	Pb Air Conc. ug/m ³
1	112.1	<75	<0.7	<0.9	<0.01
2	125.8	<75	<0.6	<0.9	<0.01
3	43	<75	<1.7	<0.9	<0.02
4	42.3	<75	<1.8	<0.9	<0.02
5	46.6	<75	<1.6	<0.9	<0.02
6	42.9	<75	<1.7	<0.9	<0.02
7	17.1	<75	<4.4	<0.9	<0.05
8	15.6	<75	<4.8	<0.9	<0.06
9	Blank	<75	N/A	<0.9	N/A
10	Blank	<75	N/A	<0.9	N/A

7. RISK CHARACTERIZATION

7.1 Overview

The modeling results for the various burn rate and mass scenarios in both the initial screening and final assessments were compared to relevant exposure guidelines in order to determine quantitative estimates of health risk for populations potentially impacted by ABL burning ground operations. This report chapter contains two sections: The first outlines risk characteristics using the screening analysis results. The second section characterizes the risk for hydrogen chloride and lead using a final, more refined, burn scenario and air dispersion analysis.

7.2 Preliminary Screening Analysis Results

In our screening evaluation, we used the modeling results in two exposure scenarios: namely, a worst and probable case exposure scenario. Prior to the presentation of the quantitative risk results, the rationale for each of these is given.

7.2.1 Worst Case Exposure

The worst case exposure evaluation takes the modeled results for the maximum allowable daily burn pan limits, as specified in the consent order between ABL and the State of West Virginia, as described in the previous section, and makes the conservative assumption that this level of burn activity occurs every working day throughout the entire year. Normal working days are taken to be weekdays such that the maximum total number of days per year with burning activity would then be 261. On occasion, burning activity is conducted on weekends if burning cannot be done one or more days in the week because of weather restrictions. This daily burning results in a multiplier of 0.72 (261/365) which is applied to the worst case hourly average from the modeling results to arrive at an annualized hourly average concentration for comparison with the exposure guidelines.

7.2.2 Probable Case Exposure

The probable case exposure takes the model results for the maximum allowable daily burn pan limits along with estimates of total burning ground P/E and P/E-contaminated waste mass obtained from ABL production schedules for calendar year 1995, as shown previously in Table 2-4. Estimates are that 38,000 kg of pure P/E waste and 77,000 kg of P/E-contaminated waste are to be sent to the burning ground in 1995. We have calculated the number of days of burning that would result if daily burn pan limits are used whenever burning is conducted. The results are as follows:

Pure P/E Waste: 38,000 kg total @ 500 kg/day max. = 76 burning days

P/E-contaminated Waste: 77,000 kg total @ 250 kg/day max = 304 burning days

Thus, the multiplier for Pure P/E waste burning for the probable exposure would be 0.21 (76/365). At first glance the multiplier for the P/E-contaminated waste would be the ratio of 304 to 365; however, P/E contaminated waste burning normally occurs a maximum of five days per week with a Consent Order limit of 500 lbs. per day (<250

kg/day). The maximum allowable number of burning days would then be 261 and the multiplier would be 0.72 which is the same as for the worst case condition. The annualized 1-hour average exposure level will be lower for the probable case than for the worst case for the pure propellant disposal operations since fewer burning days are encountered throughout the year. Specific quantitative risk results for the worst case and probable case exposures for the three burn scenarios are given in the following paragraphs along with some interpretation and discussion of results.

7.2.3 Case No. 1 High Burn Rate Scenario - Screening Meteorology

7.2.3.1 Worst Case Exposure

Risk characterization results for the 500 kg high burn rate scenario are given in Table 7-1. For this scenario, a HCl release was modeled as a puff and worst case 1-hour average and maximum instantaneous exposure levels were estimated downwind at receptor heights ranging from 0 to 200 meters above the burning ground elevation. These data, shown earlier in Figure 6-2, were interpreted in light of the local topography to extract a worst-case exposure level within the designated receptor field. The maximum off-site exposure level was a 1-hour average of 0.5 ppm corresponding to a location approximately 2,250 m along a 60 degree radial from the center of the burning ground. This corresponds to a maximum instantaneous exposure level of about 15 ppm HCl. Higher HCl concentration levels are observed on the curves shown in Figure 6-2 however these occur at locations close to the source and are above underlying receptor points such that ground level exposure to these high HCl gas concentrations would not be possible. These data for HCl were scaled for all target species by using the emission factor ratio of the target species to that of HCl. The scaled values are given in the third column of Table 7-1.

Correction factors that are applied to the maximum hourly average of 0.5 ppmv HCl are shown below along with rationale for each

- A multiplier of 0.042 (1/24) to account for the fact that exposure to the puff from a single 500 kg burn would be expected to persist for 1 hour of each day.
- A multiplier of 0.72 (5/7) to account for the fact that burning can only be carried out on normal (Monday - Friday) work days.

The burn duration is on the order of 100 seconds at this high burn rate. Puff diameter is in the range of 200-400 m at a range of 2 km. At a low wind speed of 1.5 m/s which was used in the model runs, the time for puff passage over a given receptor point is on the order of 3 to 5 minutes. Even under lower wind speed conditions, the plume residence time at a particular receptor point would not exceed one hour.

As noted in Section 7.1.1, a correction factor is applied to this 0.5 ppmv HCl hourly average to account for the fact that burning occurs only on work days and not on weekends. Although the facility is allowed to burn a maximum of 1960 lbs/day

Table 7-1 Risk Characterization Results for the Worst Case High Burn Rate Scenario

Chemical Species	EF g/g	Max 1hr ug/m ³	Corr 24-hr ug/m ³	RBC/NOAEL ug/m ³	HQ/Risk
nitrogen dioxide	5.9E-04	2.1E+00	6.2E-02	100	<1
carbon monoxide	1.2E-04	4.2E-01	1.3E-02	10300	<1
sulfur dioxide	4.0E-04	1.4E+00	4.2E-02	365	<1
pm-10	5.7E-02	2.0E+02	5.9E+00	150	<1
hcl	2.1E-01	7.4E+02	2.2E+01	7.3	3
aluminum	1.0E-01	3.5E+02	1.0E+01	3700	<1
lead	8.8E-03	3.1E+01	9.2E-01	1.5	<1
zirconium	0.0E+00	0.0E+00	0.0E+00	N/A	
copper	0.0E+00	0.0E+00	0.0E+00	N/A	
molybdenum	0.0E+00	0.0E+00	0.0E+00	N/A	
n-hexane	-2.2E-05	-7.7E-02	-2.3E-03	210	<1
benzene	1.1E-03	3.9E+00	1.1E-01	0.22	<10 ⁻⁶
xylenes	8.6E-05	3.0E-01	9.0E-03	310	<1
mesitylene	5.9E-08	2.1E-04	6.2E-06	1.5	<1
phenol	2.8E-06	9.8E-03	2.9E-04	2200	<1
naphthalene	3.9E-06	1.4E-02	4.1E-04	N/A	
thianaphthene	-8.5E-08	-3.0E-04	-8.9E-06	N/A	
resorcinol	5.5E-06	1.9E-02	5.7E-04	N/A	
2-methylnaphthalene	9.3E-06	3.3E-02	9.7E-04	N/A	
1-methylnaphthalene	2.4E-06	8.4E-03	2.5E-04	N/A	
triacetine	-9.0E-08	-3.2E-04	-9.4E-06	N/A	
biphenyl	4.7E-06	1.6E-02	4.9E-04	180	<1
2,6-dinitrotoluene	5.8E-06	2.0E-02	6.0E-04	3.7	<1
dibenzofuran	1.0E-06	3.5E-03	1.0E-04	15	<1
4-nitrophenol	-9.0E-08	-3.2E-04	-9.4E-06	230	<1
2,4-dinitrotoluene	5.8E-06	2.0E-02	6.0E-04	7.3	<1
di-n-propyl adipate	-2.7E-06	-9.5E-03	-2.8E-04	N/A	
diphenylamine	1.9E-07	6.7E-04	2.0E-05	91	<1
2-nitronaphthalene	1.7E-06	6.0E-03	1.8E-04	N/A	
phenanthrene	2.0E-06	7.0E-03	2.1E-04	N/A	
2,5-diphenyloxazole	9.5E-07	3.3E-03	9.9E-05	N/A	
N-nitrosodiphenylamine	-9.0E-08	-3.2E-04	-9.4E-06	N/A	
pyrene	-9.0E-08	-3.2E-04	-9.4E-06	110	<1
4-nitrosodiphenylamine	-9.0E-08	-3.2E-04	-9.4E-06	N/A	
benz[a]anthracene	-9.0E-08	-3.2E-04	-9.4E-06	0.01	<10 ⁻⁶
1-nitropyrene	-4.4E-06	-1.5E-02	-4.6E-04	N/A	
benzo[a]pyrene	-9.0E-08	-3.2E-04	-9.4E-06	0.001	<10 ⁻⁶
1,6-dinitropyrene	-9.0E-08	-3.2E-04	-9.4E-06	N/A	
dibenz[a,h]anthracene	-9.0E-08	-3.2E-04	-9.4E-06	0.001	<10 ⁻⁶
dioxin	-6.5E-07	-2.3E-03	-6.8E-05	0.00000005	>10 ⁻⁶

Notes:

N/A = no data available

EF = emission factor

RBC = risk based concentration

NOAEL = no observable adverse effect level

HQ = hazard quotient

24 hr correction (1 burn/dy; 1 hr/dy; 261dy/yr)

Negative concentration entries denote non-detectable concentrations at method detection limit

Species in bold are carcinogens

(<1,000 kg/day) of P/E waste, by the Consent Order, this can only occur every other day so in terms of an annualized average, either scenario (980 lbs [<500 kg] per day or 1960 lbs. [<1000 kg] every other day) produces the same annual average.

The 1-hour average concentration was multiplied by both of the above correction factors to derive the column entitled "Corr 24-hr" in Table 7-1, which is a time-weighted 24-hour average that would be expected under chronic exposure conditions. This value was then divided by the risk based concentration for carcinogenic materials or the NOAEL (Column 4) for the non-carcinogenic species to derive a quantitative risk estimate or hazard quotient (Column 5). Risk levels greater than 10^{-6} or hazard quotients less than 1 are understood to constitute unacceptable risk.

The only detected target species which exceeds acceptable risk levels for the high burn rate scenario is HCl with a hazard quotient of 3. Other potential contaminants such as lead and benzene have hazard quotients less than 1 or a target risk of 1×10^{-6} . Dioxins were not detected in any of the samples collected during emission factor testing, however, the target risk criterion is exceeded ($\text{Risk} > 10^{-6}$) even at the detection level reported from the analysis laboratory since the RBC for dioxin is a very low ($5 \times 10^{-8} \mu\text{g}/\text{m}^3$) number. See Section 7.5 for a refined analysis of potential dioxin risk.

7.2.3.2 Probable-Case Exposure

The probable case exposure differs from the worst case exposure in that 76 burning days per year are used instead of 261 burning days per year. This results in an approximate 71% reduction in the annualized 1-hour averages obtained for the worst case scenario given in Table 7-1. The hydrogen chloride gas exposure level in the probable case drops to a hazard quotient of less than 1 (0.9). Although dioxin was undetected in the samples, carrying the lab detection limit through the calculations results a detection limit exposure level that still exceeds the dioxin RBC.

7.2.4 Case No. 2 Intermediate Burn Rate Scenario - Screening Meteorology

7.2.4.1 Worst Case Exposure

Risk characterization results for the 500 kg medium burn rate scenario are given in Table 7-2. For this scenario, a Pb release was modeled in a continuous plume and the highest 1-hour average was extracted from the calculated results from 360 receptor sites within the polar receptor grid. The maximum off-site exposure level in the receptor field was a 1-hour average Pb concentration of $10 \mu\text{g}/\text{m}^3$ observed at numerous off-site locations around the plant boundary. These results for Pb were scaled to all target species shown in the table by using the emission factor ratio of the target species to that of Pb. We included the highest target analyte emission factor encountered in testing any of the pure energetics in the computation. Concentration estimates for each of the target analytes are given in the third column of the table. A correction was then applied to account for the fact that burning does

Table 7-2 Risk Characterization Results for the Worst Case Medium Burn Rate Scenario

Chemical Species	EF g/g	Max 1hr ug/m ³	Corr 24-hr ug/m ³	RBC ug/m ³	HQ/Risk
nitrogen dioxide	6.0E-04	7.1E-01	2.1E-02	100	<1
carbon monoxide	3.0E-03	3.5E+00	1.1E-01	10300	<1
sulfur dioxide	2.0E-03	2.4E+00	7.0E-02	365	<1
pm-10	1.0E-02	1.2E+01	3.5E-01	150	<1
hcl	2.6E-01	3.1E+02	9.1E+00	7.3	1
aluminum	1.0E-01	1.2E+02	3.5E+00	3700	<1
lead	8.8E-03	1.0E+01	3.1E-01	1.5	<1
zirconium	9.0E-05	1.1E-01	3.2E-03	N/A	
copper	2.0E-05	2.4E-02	7.0E-04	N/A	
molybdenum	5.0E-04	5.9E-01	1.8E-02	N/A	
n-hexane	1.0E-03	1.2E+00	3.5E-02	210	<1
benzene	1.0E-03	1.2E+00	3.5E-02	0.22	<10 ⁻⁶
xylenes	9.0E-05	1.1E-01	3.2E-03	310	<1
mesitylene	3.0E-07	3.5E-04	1.1E-05	1.5	<1
phenol	2.0E-07	2.4E-04	7.0E-06	2200	<1
naphthalene	4.0E-06	4.7E-03	1.4E-04	N/A	
thianaphthene	-1.0E-07	-1.2E-04	-3.5E-06	N/A	
resorcinol	3.0E-06	3.5E-03	1.1E-04	N/A	
2-methylnaphthalene	2.0E-05	2.4E-02	7.0E-04	N/A	
1-methylnaphthalene	3.0E-06	3.5E-03	1.1E-04	N/A	
tracetine	-1.0E-07	-1.2E-04	-3.5E-06	N/A	
biphenyl	1.0E-06	1.2E-03	3.5E-05	180	<1
2,6-dinitrotoluene	1.0E-05	1.2E-02	3.5E-04	3.7	<1
dibenzofuran	2.0E-06	2.4E-03	7.0E-05	15	<1
4-nitrophenol	-1.0E-07	-1.2E-04	-3.5E-06	230	<1
2,4-dinitrotoluene	-1.0E-07	-1.2E-04	-3.5E-06	7.3	<1
di-n-propyl adipate	4.0E-07	4.7E-04	1.4E-05	N/A	
diphenylamine	2.0E-07	2.4E-04	7.0E-06	91	<1
2-nitronaphthalene	2.0E-07	2.4E-04	7.0E-06	N/A	
phenanthrene	3.0E-06	3.5E-03	1.1E-04	N/A	
2,5-diphenyloxazole	2.0E-06	2.4E-03	7.0E-05	N/A	
N-nitrosodiphenylamine	-1.0E-07	-1.2E-04	-3.5E-06	N/A	
pyrene	-1.0E-07	-1.2E-04	-3.5E-06	110	<1
4-nitrosodiphenylamine	-1.0E-07	-1.2E-04	-3.5E-06	N/A	
benz[a]anthracene	-1.0E-07	-1.2E-04	-3.5E-06	0.01	<10 ⁻⁶
1-nitropyrene	-1.0E-07	-1.2E-04	-3.5E-06	N/A	
benzo[a]pyrene	-1.0E-07	-1.2E-04	-3.5E-06	0.001	<10 ⁻⁶
1,6-dinitropyrene	-1.0E-07	-1.2E-04	-3.5E-06	N/A	
dibenz[a,h]anthracene	-1.0E-07	-1.2E-04	-3.5E-06	0.001	<10 ⁻⁶
dioxin	-0.00000065	-7.7E-04	-2.3E-05	0.00000005	>10 ⁻⁶

Notes:

N/A = no data available

EF = emission factor

RBC = risk based concentration

NOAEL = no observable adverse effect level

HQ = hazard quotient

24 hr correction (1 burn/dy; 1 hr/dy; 261dy/yr)

Negative concentration entries denote non-detectable concentrations at method detection limit

Species in bold are carcinogens

not occur over an entire 24-hour interval. In the case of the medium burn rate scenario, the following multipliers were used:

- A multiplier of 0.042 (1/24) to account for the fact that exposure to the plume from an intermediate rate burn could persist for a period of about one hour.
- A multiplier of 0.72 (5/7) to account for the fact that burning can only be carried out on normal (Monday - Friday) work days.

The burn time for a 500 kg burn at a 200 g/s burn rate is about 40 minutes. Thus, plume exposure would be expected to persist for about 1 hour per day.

The 1-hour average concentration was multiplied by both of the above correction factors to derive the column entitled "Corr 24-hr", shown in Table 7-2, which is the annualized 24-hour average that would be expected under chronic exposure conditions. This value was then divided by the risk based concentration for carcinogenic materials or the NOAEL for the non-carcinogenic species to derive a quantitative risk estimate or hazard quotient. Risk levels greater than 10^{-6} or hazard quotients greater than 1 are understood to constitute unacceptable risk.

As in the high burn rate case, the only detected target species which exceeded acceptable exposure levels for the medium burn rate scenario was HCl with a hazard quotient of 1.2. Lead, benzene and other target analytes of interest have hazard quotients significantly less than 1 or risk factors less than 1×10^{-6} . Dioxins were not detected in any of the samples collected during emission factor testing, however, the risk criterion is exceeded even at the detection level reported from the analysis laboratory. See Section 7.5 for a refined analysis of potential dioxin risk.

7.2.4.2 Probable Case Exposure

The probable case exposure in the intermediate burning rate scenario differs from the worst case exposure in that 76 burning days per year are used instead of 261 burning days per year. This results in an approximate 71% reduction in the annualized 1-hour averages obtained for the worst case scenario given in Table 7-2. For this scenario, the HCl hazard quotient drops to a value of less than 1 (0.4). All other species remain below a hazard quotient of 1 or a target risk of 1×10^{-6} with the exception of dioxin which although undetected is still reported at a concentration level in excess of the target risk level.

7.2.5 Case No. 3 Low Burn Rate Scenario - Screening Meteorology

7.2.5.1 Worst Case Exposure

- Risk characterization results for a 500 kg low burn rate scenario are given in Table 7-3. For this scenario, a CO release was modeled in a continuous plume and the highest 1-hour average was extracted from the calculated results from 360 receptor sites within the polar receptor grid. The maximum off-site exposure level in the receptor field was a 1-hour average CO concentration of 0.66 mg/m^3 at a receptor directly north of the burning ground. Results for CO were scaled to all target species shown in the table

Table 7-3 Risk Characterization Results for the Worst Case Low Burn Rate Scenario

Chemical Species	EF g/g	Max 1hr ug/m ³	Corr 24-hr ug/m ³	RBC ug/m ³	HQ/Risk
nitrogen dioxide	1.1E-03	2.1E+00	2.2E-01	100	<1
carbon monoxide	3.5E-01	6.6E+02	6.9E+01	10300	<1
sulfur dioxide	7.6E-04	2.3E-02	2.4E-03	365	<1
pm-10	7.4E-03	2.2E-01	2.3E-02	150	<1
hcl	1.4E-02	4.2E-01	4.4E-02	7.3	<1
aluminum	5.0E-03	1.5E-01	1.6E-02	3700	<1
lead	9.8E-04	1.0E+01	1.1E+00	1.5	<1
zirconium	9.8E-04	3.0E-02	3.1E-03	N/A	
copper	2.0E-05	6.0E-04	6.3E-05	N/A	
molybdenum	5.0E-04	1.5E-02	1.6E-03	N/A	
n-hexane	3.3E-04	9.9E-03	1.0E-03	210	<1
benzene	3.3E-04	9.9E-03	1.0E-03	0.22	<10 ^b
xylenes	3.3E-04	9.9E-03	1.0E-03	310	<1
mesitylene	-1.0E-08	-3.0E-07	-3.2E-08	1.5	<1
phenol	-1.0E-08	-3.0E-07	-3.2E-08	2200	<1
naphthalene	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
thianaphthene	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
resorcinol	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
2-methylnaphthalene	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
1-methylnaphthalene	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
tracetine	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
biphenyl	-1.0E-08	-3.0E-07	-3.2E-08	180	<1
2,6-dinitrotoluene	-1.0E-08	-3.0E-07	-3.2E-08	3.7	<1
dibenzofuran	-1.0E-08	-3.0E-07	-3.2E-08	15	<1
4-nitrophenol	-1.0E-08	-3.0E-07	-3.2E-08	230	<1
2,4-dinitrotoluene	-1.0E-08	-3.0E-07	-3.2E-08	7.3	<1
di-n-propyl adipate	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
diphenylamine	-1.0E-08	-3.0E-07	-3.2E-08	91	<1
2-nitronaphthalene	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
phenanthrene	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
2,5-diphenyloxazole	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
N-nitrosodiphenylamine	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
pyrene	-1.0E-08	-3.0E-07	-3.2E-08	110	<1
4-nitrosodiphenylamine	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
benz[a]anthracene	-1.0E-08	-3.0E-07	-3.2E-08	0.01	<10 ^b
1-nitropyrene	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
benzo[a]pyrene	-1.0E-08	-3.0E-07	-3.2E-08	0.001	<10 ^b
1,6-dinitropyrene	-1.0E-08	-3.0E-07	-3.2E-08	N/A	
dibenz[a,h]anthracene	-1.0E-08	-3.0E-07	-3.2E-08	0.001	<10 ^b
dioxin	-0.00000065	-2.0E-05	-2.1E-06	0.00000005	>10 ^b

Notes:

N/A = no data available

EF = emission factor

RBC = risk based concentration

NOAEL = no observable adverse effect level

HQ = hazard quotient

24 hr correction (1 burn/dy; 7 hr/dy; 131dy/yr)

Negative concentration entries denote non-detectable concentrations at method detection limit

Species in bold are carcinogens

by using the emission factor ratio of the target species to that of CO. The highest emission factor for each of the target analytes was selected from the chamber testing results for the P/E-contaminated burns. These results are given in the third column of the table. Correction factors to account for non-continuous burning throughout the year that were applied to this maximum hourly average are given below.

- A multiplier of 0.29 (7/24) to account for the fact that exposure to the plume from a single burn could persist up to 7 hours. This exposure time assumes two simultaneous 250 kg burns at a burn rate of 10 g/s with commingled plumes.
- A multiplier of 0.36 (131/365) to account for the fact that burning of 500 kg P/E-contaminated waste batches can only be carried out every other work day (Monday - Friday) according to the terms of the consent order.

The 1-hour average concentration was multiplied by both of the above correction factors to derive the column entitled "Corr 24-hr" which is the time weighted 24-hour average that would be expected for a chronic exposure. This value was then divided by the risk based concentration for carcinogenic materials or the NOAEL for the non-carcinogenic species to derive a quantitative risk estimate or hazard quotient.

None of the detected target species exposure concentrations resulted in hazard quotients greater than 1. Airborne lead shows an HQ of 0.7 with all other species significantly less than 1. Dioxins were not detected in any of the samples collected during emission factor testing, however, the dioxin risk criterion of 1×10^{-6} is exceeded even at the detection level reported from the analysis laboratory. See Section 7.5 for a refined analysis of potential dioxin risk.

7.2.5.2 Probable Case Exposure

The probable case exposure in the P/E-contaminated waste low burn rate scenario is the same as the worst case since the anticipated waste mass is greater than what can be legitimately burned under the terms of the consent order. Consequently, hazard quotients for target analyte non-carcinogens remain at values less than 1 and at target risks for carcinogens also less than 1×10^{-6} . Dioxins were not detected in any of the samples collected during emission factor testing, however, the dioxin target risk criterion of 1×10^{-6} is exceeded even at the detection level reported from the analysis laboratory.

7.2.6 Case No. 4 Intermediate Burn Rate Scenario - On-site Meteorology

7.2.6.1 Worst Case Exposure

Risk characterization results for the 500 kg medium burn rate scenario are given in Table 7-4. For this scenario, a Pb release was modeled in a continuous plume and the highest 1-hour average was extracted from the calculated results for 360 receptor sites within the polar receptor grid and the 36 sites along the plant boundary. In this evaluation, one year of on-site meteorological data was used. The maximum off-site exposure level in the receptor field was a 1-hour average Pb concentration of 55 ug/m^3 observed at numerous off-site locations around the plant boundary. These results for Pb were scaled to all target species shown in the table by using the

emission factor ratio of the target species to that of Pb. We included the highest target analyte emission factor encountered in testing any of the pure energetics in the computation. Maximum 1-hour average receptor site concentration estimates for each of the target analytes are given in the third column of the table. A correction was then applied to account for the fact that burning does not occur over an entire 24-hour interval. In the case of the medium burn rate scenario, the following multipliers were used:

- A multiplier of 0.042 (1/24) to account for the fact that exposure to the plume from a intermediate rate burn could persist for a period of about one hour.
- A multiplier of 0.72 (5/7) to account for the fact that burning can only be carried out on normal (Monday - Friday) work days.

The burn time for a 500 kg burn at a 200 g/s burn rate is about 40 minutes. Thus, plume exposure would be expected to persist for about 1 hour per day.

The 1-hour average concentration was multiplied by both of the above correction factors to derive the column entitled "Corr 24-hr", shown in Table 7-4, which is the annualized 24-hour average that would be expected under chronic exposure conditions. This value was then divided by the risk based concentration for carcinogenic materials or the NOAEL for the non-carcinogenic species to derive a quantitative risk estimate or hazard quotient. Risk levels greater than 10^{-6} or hazard quotients greater than 1 are understood to constitute unacceptable risk.

As in the high burn rate case, the only detected target species which exceeded acceptable exposure levels for the medium burn rate scenario was HCl with a hazard quotient of 6.7 and lead with a quotient of 1.1. Benzene and other target analytes of interest have hazard quotients significantly less than 1 or risk factors less than 1×10^{-6} . Dioxins were not detected in any of the samples collected during emission factor testing, however, the risk criterion is exceeded even at the detection level reported from the analysis laboratory. See Section 7.5 for a refined analysis of potential dioxin risk.

7.2.6.2 Probable Case Exposure

The probable case exposure in the intermediate burning rate scenario differs from the worst case exposure in that 76 burning days per year are used instead of 261 burning days per year. This results in an approximate 71% reduction in the annualized 1-hour averages obtained for the worst case scenario given in Table 7-4. For this scenario, the HCl hazard quotient drops to a value of 1.9 and lead drops below 1. All other species have hazard quotient less than 1 or a target risk less than 1×10^{-6} with the exception of dioxin which although undetected is still reported at a concentration level in excess of the target risk level. See Section 7.5 for a refined analysis of potential dioxin risk.

Table 7-4 Risk Characterization Results for the Worst Case Medium Burn Rate Scenario Using On-Site Meteorology

Chemical Species	EF g/g	Max 1hr ug/m ³	Corr 24-hr ug/m ³	RBC/NOAEL ug/m ³	HQ/Risk
nitrogen dioxide	6.0E-04	3.8E+00	1.1E-01	100	<1
carbon monoxide	3.0E-03	1.9E+01	5.6E-01	10300	<1
sulfur dioxide	2.0E-03	1.3E+01	3.7E-01	365	<1
pm-10	1.0E-02	6.3E+01	1.9E+00	150	<1
hcl	2.6E-01	1.6E+03	4.9E+01	7.3	6.7
aluminum	1.0E-01	6.3E+02	1.9E+01	3700	<1
lead	8.8E-03	5.5E+01	1.6E+00	1.5	1.1
zirconium	9.0E-05	5.7E-01	1.7E-02	N/A	<1
copper	2.0E-05	1.3E-01	3.7E-03	N/A	
molybdenum	5.0E-04	3.1E+00	9.4E-02	N/A	
n-hexane	1.0E-03	6.3E+00	1.9E-01	210	<1
benzene	1.0E-03	6.3E+00	1.9E-01	0.22	<10 ⁻⁶
xylenes	9.0E-05	5.7E-01	1.7E-02	310	<1
mesitylene	3.0E-07	1.9E-03	5.6E-05	1.5	<1
phenol	2.0E-07	1.3E-03	3.7E-05	2200	<1
naphthalene	4.0E-06	2.5E-02	7.5E-04	N/A	
thianaphthene	-1.0E-07	-6.3E-04	-1.9E-05	N/A	
resorcinol	3.0E-06	1.9E-02	5.6E-04	N/A	
2-methylnaphthalene	2.0E-05	1.3E-01	3.7E-03	N/A	
1-methylnaphthalene	3.0E-06	1.9E-02	5.6E-04	N/A	
tracetine	-1.0E-07	-6.3E-04	-1.9E-05	N/A	
biphenyl	1.0E-06	6.3E-03	1.9E-04	180	<1
2,6-dinitrotoluene	1.0E-05	6.3E-02	1.9E-03	3.7	<1
dibenzofuran	2.0E-06	1.3E-02	3.7E-04	15	<1
4-nitrophenol	-1.0E-07	-6.3E-04	-1.9E-05	230	<1
2,4-dinitrotoluene	-1.0E-07	-6.3E-04	-1.9E-05	7.3	<1
di-n-propyl adipate	4.0E-07	2.5E-03	7.5E-05	N/A	
diphenylamine	2.0E-07	1.3E-03	3.7E-05	91	<1
2-nitronaphthalene	2.0E-07	1.3E-03	3.7E-05	N/A	
phenanthrene	3.0E-06	1.9E-02	5.6E-04	N/A	
2,5-diphenyloxazole	2.0E-06	1.3E-02	3.7E-04	N/A	
N-nitrosodiphenylamine	-1.0E-07	-6.3E-04	-1.9E-05	N/A	
pyrene	-1.0E-07	-6.3E-04	-1.9E-05	110	<1
4-nitrosodiphenylamine	-1.0E-07	-6.3E-04	-1.9E-05	N/A	
benz[a]anthracene	-1.0E-07	-6.3E-04	-1.9E-05	0.01	<10 ⁻⁶
1-nitropyrene	-1.0E-07	-6.3E-04	-1.9E-05	N/A	
benzo[a]pyrene	-1.0E-07	-6.3E-04	-1.9E-05	0.001	<10 ⁻⁶
1,6-dinitropyrene	-1.0E-07	-6.3E-04	-1.9E-05	N/A	
dibenz[a,h]anthracene	-1.0E-07	-6.3E-04	-1.9E-05	0.001	<10 ⁻⁶
dioxin	-6.5E-07	-4.1E-03	-1.2E-04	5E-08	>10 ⁻⁶

Notes:

N/A = no data available

EF = emission factor

RBC = risk based concentration

NOAEL = no observable adverse effect level

HQ = hazard quotient

24 hr correction (1 burn/dy; 7 hr/dy; 131dy/yr)

Negative concentration entries denote non-detectable concentrations at method detection limit

Species in bold are carcinogens

7.2.7 Case No. 5 Low Burn Rate Scenario - On-site Meteorology

7.2.7.1 Worst Case Exposure

Risk characterization results for a 500 kg low burn rate scenario are given in Table 7-5. For this scenario, a CO release was modeled, using one year of on-site meteorological data, as a continuous plume release. The highest 1-hour average was extracted from the calculated results from 360 receptor sites within the polar receptor grid and the 36 boundary sites. The maximum off-site exposure level in the receptor field was a 1-hour average CO concentration of 0.930 mg/m^3 at a plant boundary receptor directly north of the burning ground. Results for CO were scaled to all target species shown in the table by using the emission factor ratio of the target species to that of CO. The highest emission factor for each of the target analytes was selected from the chamber testing results for the P/E-contaminated burns. These results are given in the third column of the table. Correction factors to account for non-continuous burning throughout the year that were applied to this maximum hourly average are given below.

- A multiplier of 0.29 (7/24) to account for the fact that exposure to the plume from a single burn could persist up to 7 hours. This exposure time assumes two simultaneous 250 kg burns at a burn rate of 10 g/s with commingled plumes.
- A multiplier of 0.36 (131/365) to account for the fact that burning of 500 kg P/E-contaminated waste batches can only be carried out every other work day (Monday - Friday) according to the terms of the consent order.

The 1-hour average concentration was multiplied by both of the above correction factors to derive the column entitled "Corr 24-hr" which is the time weighted 24-hour average that would be expected for a chronic exposure. This value was then divided by the risk based concentration for carcinogenic materials or the NOAEL for the non-carcinogenic species to derive a quantitative risk estimate or hazard quotient.

None of the detected target species exposure concentrations resulted in hazard quotients greater than 1. For this scenario, the hazard quotients for hydrogen chloride and lead are 0.6 and 0.2 respectively. The hazard quotients for all other non-carcinogenic species were significantly less than 1. Similarly, the risk factors for the carcinogenic species were less than 10^{-6} . Dioxins were not detected in any of the samples collected during emission factor testing, however, the dioxin risk criterion of 1×10^{-6} is exceeded even at the detection level reported from the analysis laboratory. See Section 7.5 for a refined analysis of potential dioxin risk.

Table 7-5 Risk Characterization Results for the Worst Case Low Burn Rate Scenario Using On-site Meteorological Data

Chemical Species	EF g/g	Max 1hr ug/m ³	Corr 24-hr ug/m ³	RBC ug/m ³	HQ/Risk
nitrogen dioxide	1.1E-03	3.0E+00	3.1E-01	100	<1
carbon monoxide	3.5E-01	9.3E+02	9.7E+01	10300	<1
sulfur dioxide	7.6E-04	2.0E+00	2.1E-01	365	<1
pm-10	7.4E-03	2.0E+01	2.1E+00	150	<1
hcl	1.4E-02	3.8E+01	4.0E+00	7.3	<1
aluminum	5.0E-03	1.3E+01	1.4E+00	3700	<1
lead	9.8E-04	2.6E+00	2.8E-01	1.5	<1
zirconium	9.8E-04	2.6E+00	2.8E-01	N/A	<1
copper	2.0E-05	5.4E-02	5.6E-03	N/A	
molybdenum	5.0E-04	1.3E+00	1.4E-01	N/A	
n-hexane	3.3E-04	8.9E-01	9.3E-02	210	<1
benzene	3.3E-04	8.9E-01	9.3E-02	0.22	<10 ⁻⁶
xylenes	3.3E-04	8.9E-01	9.3E-02	310	<1
mesitylene	-1.0E-08	-2.7E-05	-2.8E-06	1.5	<1
phenol	-1.0E-08	-2.7E-05	-2.8E-06	2200	<1
naphthalene	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
thianaphthene	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
resorcinol	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
2-methylnaphthalene	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
1-methylnaphthalene	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
tracetine	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
biphenyl	-1.0E-08	-2.7E-05	-2.8E-06	180	<1
2,6-dinitrotoluene	-1.0E-08	-2.7E-05	-2.8E-06	3.7	<1
dibenzofuran	-1.0E-08	-2.7E-05	-2.8E-06	15	<1
4-nitrophenol	-1.0E-08	-2.7E-05	-2.8E-06	230	<1
2,4-dinitrotoluene	-1.0E-08	-2.7E-05	-2.8E-06	7.3	<1
di-n-propyl adipate	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
diphenylamine	-1.0E-08	-2.7E-05	-2.8E-06	91	<1
2-nitronaphthalene	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
phenanthrene	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
2,5-diphenyloxazole	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
N-nitrosodiphenylamine	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
pyrene	-1.0E-08	-2.7E-05	-2.8E-06	110	<10 ⁻⁶
4-nitrosodiphenylamine	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
benz[a]anthracene	-1.0E-08	-2.7E-05	-2.8E-06	0.01	<10 ⁻⁶
1-nitropyrene	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
benzo[a]pyrene	-1.0E-08	-2.7E-05	-2.8E-06	0.001	<10 ⁻⁶
1,6-dinitropyrene	-1.0E-08	-2.7E-05	-2.8E-06	N/A	
dibenz[a,h]anthracene	-1.0E-08	-2.7E-05	-2.8E-06	0.001	<10 ⁻⁶
dioxin	-6.5E-07	-1.8E-03	-1.8E-04	5E-08	>10 ⁻⁶

Notes:

N/A = no data available

EF = emission factor

RBC = risk based concentration

NOAEL = no observable adverse effect level

HQ = hazard quotient

24 hr correction (1 burn/dy; 7 hr/dy; 131dy/yr)

Negative concentration entries denote non-detectable concentrations at method detection limit

Species in bold are carcinogens

7.2.7.2 Probable Case Exposure

The probable case exposure in the P/E-contaminated waste low burn rate scenario is the same as the worst case since the anticipated waste mass is greater than what can be legitimately burned under the terms of the consent order. Consequently, hazard quotients for target analyte non-carcinogens remain at values less than 1 and at target risks for carcinogens also less than 1×10^{-6} . Dioxins were not detected in any of the samples collected during emission factor testing, however, the dioxin target risk criterion of 1×10^{-6} is exceeded even at the detection level reported from the analysis laboratory. See Section 7.5 for a refined analysis of potential dioxin risk.

7.2.8 Acute Exposure Risk Characterization

Puff model screening analysis results reveal maximum instantaneous HCl concentrations of 15 ppmv within the established receptor grid as shown earlier in Figure 6-3. This maximum instantaneous value is compared to various exposure criteria presented earlier in Section 5 to arrive at a semi-quantitative characterization of acute exposure risk. The ERPG-1 value for HCl is 3 ppmv as a 1-hour average. Model output for the worst case hourly average was 0.5 ppmv which is below this exposure criteria. The other two criteria include the OSHA PEL value of 5 ppmv ceiling concentration not to be exceeded—primarily intended for worker populations; and, a screening level of one-tenth of the NIOSH IDLH value of 100 ppmv or 10 ppmv. In both cases the estimated instantaneous HCl level obtained from the model is in excess of the exposure criteria suggesting that under worst case conditions, unacceptable exposure conditions might exist off-site during fast rate propellant burns containing ammonium perchlorate. The puff model assumes a constant wind direction in the calculations resulting in a very narrow plume. An argument can be made however, that wind meander, the inherent variability of wind direction over time, would serve to reduce peak instantaneous HCl concentrations to lower acceptable levels by distributing the plume over a wider downwind footprint. On the other hand, a fast burn rate is under consideration here however. The passage time of the puff over a particular receptor site is on the order of minutes and would consequently be less susceptible to the averaging effects of wind meander that generally occur over longer time scales. A more detailed analysis of hydrogen chloride risk characterization was carried out as a part of the final modeling analysis and is described in the following paragraphs. Additional information on exposure risk to HCl is also given in the section describing on-site measurement results.

7.3 Final Analysis Results

7.3.1 Cases A1, A2, C1, and C2 Risk Characterization Results

7.3.1.1 Hydrogen Chloride Exposure Criteria

A number of exposure criteria for acute HCl exposure were outlined in Section 5. For the reader's convenience, these exposure criteria are briefly summarized below:

EPA Screening Level - The NIOSH Immediately Dangerous to Life and Health (IDLH) value is used as a reference value for the EPA screening level which is 10% of the IDLH value. For HCl, the screening level is 10 ppmv—a ceiling value not be exceeded.

ACGIH and NIOSH Occupation Exposure Guidelines - Current occupational exposure guidelines for HCl exposures are set at a 5 ppmv ceiling value which should not be exceeded at any time. These exposure standards are intended for occupational use only and are generally not suitable for general population exposure assessment.

ACGIH Emergency Response Planning Guidelines - Three levels of exposures with varying degrees of conservatism are called out for HCl:

EPRG-1 (most conservative—mild transient adverse health effects, noticeable odor): 1-hour exposure maximum concentration not to exceed 3 ppmv HCl.

EPRG-2 (moderately conservative—no irreversible adverse health effects): 1-hour exposure maximum concentration not to exceed 20 ppmv HCl.

EPRG-3 (least conservative—no life threatening health effects): 1-hour exposure maximum not to exceed 100 ppmv HCl.

US Air Force Space Command - The Air Force has established a three tier exposure system for use in evaluating HCl exposure to the general public who may be exposed to plumes from rocket launches. Tier 1, which is the most conservative and appropriate for this case, calls for a 1-hour time weighted average of 2 ppmv with a ceiling value of 10 ppmv.

7.3.1.2 Comparison of Expected Levels to Exposure Criteria

The three highest peak HCl exposure levels at or outside of ABL boundary lines for Case A1, shown in Table 7-6 are in the range of 7 to 10 ppmv. Corresponding 1-hour averages are about 0.2 ppmv since burns are of relatively short duration. These levels fall below all acute exposure criteria noted above except the EPRG-1 guideline, since that particular guideline calls for a ceiling value of 3 ppmv. Results for Case A2, the slower burn rate, are similar since, as noted previously in Section 6, peak values drop by about 15% when compared to Case A1 results.

Table 7-6 Case A1: Highest three peak instantaneous and average HCl concentrations

Impact Region Severity Level	HCl Concentration, ppmv		
	Peak Instantaneous	2-min average	1-hour average
Highest Conc.	9.5	7	0.2
2 nd Highest Conc.	8.7	6	0.2
3 rd Highest Conc.	7.5	5	0.2

The three highest peak HCl levels at or outside ABL boundary lines for Case C1, shown in Table 7-7, fall in the range of 10 to 12 ppmv. They are slightly in excess of the exposure guidelines however not by a significant factor. The two minute averages are all below 10 ppmv revealing that exposures are of short duration. Hourly averages are in the vicinity of 0.2 ppmv. Results for Case C2 are lower by about 15%, and thus fall very near the 10 ppmv ceiling limit.

Table 7-7 Case C1: Peak and Time Weighted Average HCl Concentrations for the High Three Occurrences

Impact Region Severity Level	HCl Concentration, ppmv		
	Peak Instantaneous	2-min average	1-hour average
Highest Conc.	12.0	7.7	0.2
2 nd Highest Conc.	12.0	7.7	0.2
3 rd Highest Conc.	10.5	7.0	0.2

7.3.1.3 Risk Characterization Conclusions—Acute HCl Exposure

The potential for adverse health effects from occasional exposure to HCl is not judged to be significant from disposal operations currently being carried out at the existing ABL burn site. The proximity of Route 956 to the points of maximum plume impact along the ridge east of the ABL plant suggests that HCl odors might be encountered by motorists or pedestrians along this route however only minimal discomfort would be expected. These instances would occur primarily during high burn rate disposal operations which occur infrequently based on composite propellant burn rate data from the ABL burn site that has been compiled over the past year. Most of the material burns at rates near the average value of 800 g/s resulting in correspondingly lower peak HCl levels and generally well below applicable exposure criteria.

The potential for long-term, irreversible, adverse health effects from the alternate burn site is judged to be insignificant. Noticeable odors and slight discomfort could be occasionally encountered by motorists or pedestrians along the western face of Knobly Mountain along Route 956, however these effects would be transient in nature.

7.3.2 Cases B and D Risk Characterization Results

7.3.2.1 Lead Exposure Criteria

The WV Office of Air Quality has suggested one possible approach for derivation of Pb exposure criteria as follows: A quarterly average Pb concentration of 1.5 ug/m³, derived from the National Ambient Air Quality Standard is used as a starting point. A factor of 0.6 is used in going from a quarterly to annual average to account for seasonal variations in average Pb concentrations from a steady state source as a result of meteorological influences. The adjusted target annual average is then 0.9 ug/m³. Since Pb emissions can occur from multiple industrial processes and vehicle use, a single source is allowed to contribute no more than 10% to the adjusted annual average. This factor drops the allowable annual average Pb concentration from a single source, such as the ABL burning ground, to 0.09 ug/m³.

7.3.2.2 Comparison of Expected Levels to Criteria

Annual average Pb concentrations, summarized for Case B and D in Tables 7-8 and 7-9 respectively, indicate that all computed maximum annual average Pb concentrations fall well below the target level of 0.09 ug/m³. Annual average levels are in the range of 0.01 to 0.02 ug/m³ for Cases B and D. In all but one instance, these maximum values are encountered at receptor sites within ABL plant boundaries. Concentration at receptor sites on or outside plant boundaries are lower than those noted here. Furthermore, as noted previously, these annual average determinations are very much worst case since they assume one burn per hour between the hours of 9AM and 4PM each day of the year. Based on estimates of expected waste material, actual burn activity of Pb-containing double base propellant would be less than 10% of the burn activity level assumed in the modeled burn scenario. Actual maximum annual average Pb exposures would be correspondingly lower, probably in the range of 0.001 to 0.002 ug/m³ and well under the target level of 0.09 ug/m³.

Table 7-8 Case B: Existing Site/Double Base Modeling Results

Type of Occurrence	Site Location UTM Easting / Northing / Elev (m)	Pb Concentration, ug/m ³
Highest 1-hour average	687293 / 4380787 / 396	17.6
2 nd high 1-hour average	687479 / 4380955 / 356	11.0
3 rd high 1-hour average	687207 / 4380401 / 312	5.8
Highest annual average ¹	686050 / 4381630 / 213	0.021
2 nd high annual average	686050 / 4381480 / 213	0.016
3 rd high annual average	688118 / 4381416 / 413	0.011

¹ Note that the computed annual averages are **conservative** values since the assumption is made that a burn occurs every hour between 9AM and 4PM every week day of the year. Anticipated burn mass, based on plant production, would result in considerably less (<10%) of the assumed burn activity in this model run.

Table 7-9 Case D Alternate Site/Double Base Modeling Results

Type of Occurrence	Site Location UTM Easting / Northing / Elev. (m)	Pb Concentration, ug/m ³
Highest 1-hour average Screening Met	685790 / 4380065 / 412	26.2
2 nd high 1-hour average Screening Met	685790 / 4380065 / 412	26.2
3 rd high 1-hour average Screening Met	685790 / 4380065 / 412	26.2
Highest 1-hour average On-site Met	685148 / 4380526 / 263	10.8
2 nd high 1-hour average On-site Met	685148 / 4380526 / 263	9.6
3 rd high 1-hour average On-site Met	685148 / 4380526 / 263	9.0
Highest annual average On-site Met	685148 / 4380526 / 263	0.026
2 nd high annual average On-site Met	685148 / 4380474 / 262	0.023
3 rd high annual average On-Site Met	685790 / 4380065 / 412	0.017

Note that the computed annual averages are **conservative** values since it was assumed that a burn occurs every hour between 9AM and 4PM every week of the year. Anticipated burn mass, based on plant production, would result in considerably less (about 5%) of the assumed burn activity in this model run.

7.3.2.3 Risk Characterization Conclusions - Chronic Pb Exposure

The results of dispersion modeling analyses for ABL burn activity involving Pb-containing double base propellant reveal that annual average Pb concentrations at maximally impacted receptor sites would be less than the target risk concentration of 0.09 ug/m³ by a factor of ten or more. No adverse health effects resulting from chronic exposure to Pb are expected to result from burn activities at the current or the potential alternate burning ground.

7.4 On-Site Sampling Results

On-site sampling results, presented earlier in Table 6-12 show that, under the limited sampling carried out in the vicinity of the burning ground, no detectable concentrations of either HCl or Pb were encountered. The equivalent air concentrations of the analysis detection levels ranged from <0.6 to <4.8 ug/m³ for HCl and <0.01 to <0.06 for Pb. These levels are below the relevant exposure criteria for a 24-hour average continuous exposure scenario. The NOAELs for HCl and Pb are 7 ug/m³ and 1.5 ug/m³ respectively. Further correction of these detection level concentrations could be made since, in most cases, the samplers were operated for periods less than 24 hours. The limited on-site sampling data reveals no ground level plume impacts in the vicinity of residential dwellings immediately north of the ABL burning ground, across the Potomac River. On at least two occasions, the burning ground plume could be observed to move directly over the samplers at

altitudes ranging from 50 to 100 meters above ground level, so it is not surprising that plume impacts were not measured at the samplers.

7.5 Risk Characterization Conclusions

Two stages of modeling analyses were used in this air pathways risk assessment. Initial screening analysis results using both worst case and probable case burn scenarios reveal that the majority of chemicals in the target analyte list, established at the onset of the project, are either not present in the plume or present at concentration levels many orders of magnitude below concentrations at which they would pose an exposure health risk to the local populace. The target list included compounds such as volatile and semi-volatile organics, acidic gases and selected heavy metals such as lead, likely to be present in the emission plume. The screening analysis revealed three compounds for which modeled downwind concentrations either exceeded or were in the range of maximum acceptable concentration levels. These compounds were: hydrogen chloride, lead, and dioxin. Potential exposure to these compounds was examined in follow-on analyses, in which the burn scenarios were refined using on-site plume temperature measurements and burn mass and duration that more closely followed the consent order between ABL and the State of West Virginia.

The final analysis results reveal that off-site hydrogen chloride levels, under high burn rate conditions are borderline in terms of acute exposure hazards. Exposure criteria calls for peak instantaneous levels not to exceed 10 ppm. In the high burn rate case for the existing disposal ground, peak instantaneous hydrogen chloride concentration levels of 10 ppm were obtained. Hourly average values were about a factor of 10 below the maximum allowable 2 ppmv time weighted average.

Final analysis results for lead exposures clearly indicate that all potential lead exposures are all well below the maximum allowable contribution to the annual average from a single source such as the ABL burning ground. Expected maximum, worst case lead exposures from ABL burning operations at off-site receptors are in the range of 0.017 - 0.026 $\mu\text{g}/\text{m}^3$ annual average. These levels are about 20% of the proposed State of WV exposure criteria of 0.09 $\mu\text{g}/\text{m}^3$ annual average allowable from a single source such as the ABL burning ground.

As noted in previous discussion, emission testing at the SNL test chamber included a dioxin screen of the semi-volatile aerosol component of the various emissions. All dioxin screen results were reported as none detected since there was no basis for estimating how far below the detection level a particular sample might have been. The detection level of the screening analysis was not as low as could be obtained if a more costly analysis was carried out. When the dioxin screen detection level was carried through the risk calculations, the resulting risk was in excess of the allowable risk. To further investigate this apparent condition of unacceptable risk, we make reference to a previous measurement program in the SNL test chamber which was carried out to specifically measure the various dioxin and dibenzofuran compounds of toxicological interest at very low detection levels following perchlorate-based propellant combustion [AMCCOM, 1992]. In this study, funded by the US Army Armament Munitions and Chemical Command, emissions from a propellant composition very similar to typical ABL hydroxy-terminated polybutadiene propellants was tested for dioxin content. No dioxin (2,3,7,8-TCDD) was detected in this study. Using very high sensitivity analysis techniques, investigators reported an emission

factor for the general class of polychlorinated dibenzodioxins (PCDD) of 2×10^{-15} g/g based on the method detection limit. In the present ABL health risk assessment, an emission factor of 6.5×10^{-7} g/g was based on the detection level of the dioxin screening method. Using the Army study PCDD emission factor in place of the conservative Sandia study factor results in an adjustment factor of 2.8×10^{-9} . Revised calculations for dioxin risk levels, using the AMCCOM study detection levels, for the risk characterization data tables (Tables 7-1 through 7-5) shown earlier in this section are presented in Table 7-10

Table 7-10 Adjusted Dioxin Concentrations

Table No.	Adjusted Dioxin 24-hr Conc. $\mu\text{g}/\text{m}^3$
7-1	2 E-13
7-2	6 E-14
7-3	6 E-15
7-4	3 E-13
7-5	5 E-13

As noted previously, the risk based concentration for dioxin is $5 \text{ E-}08 \mu\text{g}/\text{m}^3$. Thus, in all worst case and probable case burn scenarios used in the screening analysis, the potential health risk from dioxin or related polychlorinated derivatives is between 5 and 7 orders of magnitude below the acceptable risk level and thus is negligible.

Another propellant open burning emission study was recently completed by the US Army at Dugway Proving Ground. The study documentation, published in draft form March 1996, similarly reports that no 2,3,7,8-TCDD was detected following composite propellant burns. Taking into consideration the relative toxicities of the other chlorinated derivatives, the equivalent emission factors are of the same order of magnitude or lower than those discussed above in the first Army study. The second study results further support the conclusion that dioxin and related compounds are not generated during propellant combustion and that associated potential human health risk from dioxin and other PCDD's via the inhalation pathway is negligible.

8. SUMMARY AND CONCLUSIONS

An estimate of quantitative risk for a range of burning conditions was carried out for the pure propellant/explosive (P/E) and P/E-contaminated waste disposal procedures at the Allegany Ballistics Laboratory (ABL) burning ground in Rocket Center, West Virginia. The assessment relied upon a series of measurements of pollutant emissions from small-scale combustion tests of various waste materials normally encountered at the ABL burning ground that were carried out at specialized testing facilities at Sandia National Laboratories in Albuquerque, New Mexico. These tests produced a list of emission factors for number of potentially toxic chemicals likely to be released during the burning process.

The measured emission factors were incorporated into three waste burning scenarios that were used in dispersion modeling analysis for the ABL site. High, medium and low rate burn scenarios were used to cover the range of burning activities normally conducted at the burn site. High rate burns were used to characterize the faster burning pure P/E material such as the composite propellant materials. Medium rate burns were used to characterize the slower burning pure energetics such as the double base and explosives. The low rate burn scenario was used to represent the combustion of P/E-contaminated waste which is mostly cellulosic materials, solvents and some plastics.

A puff dispersion model was used to forecast the dispersion properties of the high rate burn under worst case exposure conditions. Model outputs were maximum 1-hour downwind and instantaneous maximum concentrations as a function of downwind distance and various heights above ground. The medium and low burn rate plume releases were modeled with a continuous plume dispersion model which also had the capability of taking the local topography into account. Two meteorological inputs were used in continuous plume model execution. For a preliminary analysis, an EPA meteorological screening file was used. At a later stage in the analysis, a one-year meteorological data set of hourly averages collected from an acoustic sounder and a 30-m meteorological tower at the burning ground was used.

In all three scenarios, the highest value at any point within a pre-established receptor field was scanned and extracted from the model output data. For the preliminary screening assessment, all receptors within the receptor field were considered equally and no special consideration was given to land use at any particular receptor point in the entire receptor field. For the follow-on analysis using on-site meteorological data, only receptor sites on or outside the ABL plant boundary were considered. These maximum concentration data were further classed into worst case and probable case exposure scenarios. The worst case scenario assumed burning maximum allowable burn masses every working day (261 days) for the entire year, whereas the probable case took the expected burning ground inventory for the year for the two waste categories (pure P/E and P/E contaminated waste) into account. In each case, the number of total burning days in the entire year was determined and used to adjust the 1-hour averages into an annualized average.

Adjusted 1-hour averages were compared directly with the exposure criteria associated with acceptable risk, available from a number of toxicological databases developed by the EPA. In the case of non-carcinogenic materials, a hazard quotient

was determined, which is the ratio of the expected annual average concentration to the maximum acceptable average exposure concentration. Hazard quotients greater than 1 are understood to be suggestive of unacceptable exposure conditions. In the case of carcinogenic species, a risk based concentration (RBC) was used as the maximum allowable concentration to which population groups could be exposed. The RBC corresponds to an exposure concentration to which an individual can be exposed for a lifetime while incurring a cancer risk of 10^{-6} or less. The ratio of the expected exposure concentration to the RBC for carcinogens is much like the hazard quotient with values in excess of 1 representing unacceptable exposure risk.

Chemical species that are expected to be in excess or near the acceptable exposure levels in the various screening analysis scenarios are summarized in Table 8-1. The only non-carcinogenic species with a hazard quotient greater than 1 in any of the modeling scenarios are hydrogen chloride, which is produced during the combustion of propellants containing ammonium perchlorate, and lead, which is an additive in some double base propellants. A hydrogen chloride hazard quotient of 3 was obtained in the high burn rate worst case scenario. A hazard quotient of 7 was also obtained in the worst case medium burn rate scenario using on-site meteorology. All other hydrogen chloride results were below levels of concern. Airborne lead evaluations reveal hazard quotients either less than or very near 1 in all burn rate scenarios. Benzene was the only carcinogen detected in the emissions testing however, estimated risk levels for benzene were always less than the target risk level of 1×10^{-6} . Dioxin was undetected in all samples collected in the chamber tests however when the laboratory dioxin detection level was carried through all calculations, the resulting worst case exposure concentration was above the RBC for dioxin, since the dioxin RBC is a very small number. We used dioxin analysis data from other emission tests of composite propellants, carried out at much lower detection levels, to conclude that dioxin and other polychlorinated dibenzodioxins are not produced during composite propellant combustion. The resulting worst case dioxin concentrations are 5 to 7 orders of magnitude below the dioxin RBC. All other target species, both carcinogens and non-carcinogens, that were evaluated against exposure criteria were also well below acceptable risk target levels.

Screening analysis results show that short term HCl levels exceeded applicable exposure criteria when worst case burn scenarios involving ammonium perchlorate are considered. Maximum instantaneous hydrogen chloride concentrations under worst case conditions could be as high as 15 ppmv which is greater than occupational exposure guidelines that specify a ceiling value of 5 ppmv. This anticipated level is also greater than EPA screening criteria of 10 ppmv HCl.

Table 8-1 Summary of Risk Characterization Results for all Screening Analysis Burn Conditions and Exposure Scenarios

Chemical Species	High Burn Rate		Medium Burn Rate		Low Burn Rate	
	Puff Release		Continuous Release		Continuous Release	
	Screening Meteorology		On-Site Meteorology		On-Site Meteorology	
	Worst Case	Probable Case	Worst Case	Probable Case	Worst Case	Probable Case
Non-Carcinogens: Hazard Quotient						
HCl	3.0	0.9	6.7	1.9	0.6	0.6
Lead	0.6	0.2	1.1	0.3	0.2	0.2
Carcinogens: Risk						
Benzene	5×10^{-7}	1×10^{-7}	1×10^{-6}	1×10^{-6}	1×10^{-7}	1×10^{-7}

A follow-on analysis was conducted specifically for hydrogen chloride and lead emissions using revised burn scenarios agreed upon by Sandia, ABL and WV Office of Air Quality. Additional on-site testing provided direct measurements of plume temperature which were in turn incorporated into the final modeling analysis. Refinements were also made to the modeled burn scenarios in order to more closely reflect actual operations at the burning ground. Puff dispersion analyses were carried out for high and medium rate composite propellant burns at the existing burn site and also at a proposed alternate burn site in order to estimate worst case peak and 1 hour average hydrogen chloride exposure levels. Results from these analyses are summarized in Table 8-2. Hydrogen chloride exposures at the existing burn site are just within applicable exposure criteria. Worst case acute exposures at the proposed alternate burn site are slightly (20%) in excess of applicable maximum exposure criteria.

Plume dispersion analysis were also carried out for a double base propellant containing lead additives. Analyses were carried out using on-site meteorology for the existing burn site and a proposed alternate burn site. Annual average lead concentrations were modeled at all receptor sites in the grid assuming continuous hourly burning from 9 am to 4 pm on all weekdays. Risk characterization results from these analyses are also summarized in Table 8-2. Long term exposure to lead was shown to be well below maximum exposure concentrations proposed by the State of WV Department of Air Quality.

Table 8-2 Summary of Risk Characterization Results for Final Burn Conditions and Exposure Scenarios

Toxic Species	Existing Site		Proposed Alternate Site	
	Composite Propellant High Burn Rate	Double Base Propellant Medium Burn Rate	Composite Propellant High Burn Rate	Double Base Propellant Medium Burn Rate
Hydrogen Chloride				
Modeled max. peak conc.	10 ppm	---	12 ppm	---
Recommended max. peak conc.	10 ppm	---	10 ppm	---
Modeled max. 1-hr average	0.2 ppm	---	0.2 ppm	---
Recommended max 1-hr average	2 ppm	---	2 ppm	---
Lead				
Modeled max. annual average	---	0.02 µg/m ³	---	0.03 µg/m ³
Recommended max. annual average	---	0.09 µg/m ³	---	0.09 µg/m ³

On-site plume sampling conducted over a one-week period during normal burning ground operations revealed non-detectable levels of both Cl and Pb in all samples collected. These two species are used as tracers for all plume constituents since the concentration ratio of other target species relative to the tracer species is known through the emissions characterization work carried out at the Sandia National Laboratories testing facilities in an earlier phase of the study. In all cases the detection level concentration of the target species was below either the hazard quotient of non-carcinogenic target species or the risk based concentration of carcinogenic target species.

9. REFERENCES

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Appendix A INITIAL SCREENING ANALYSIS : DESCRIPTION AND RESULTS

Introduction

This appendix contains a complete description of the burn scenarios and the model inputs used for the initial screening analysis. Screening analysis results are summarized in the main body of the report however, the procedural details are included in this appendix only.

Approach

Exposure assessment in the screening phase of the project was carried out for three distinct burn scenarios in five modeling runs by using the burn characteristics and target analyte emission factors as the source term in a dispersion model evaluation. Worst-case meteorology was used in three screening runs of the models to determine the highest 1-hour exposure concentration likely to be observed for the range of species on the target analyte list anywhere within a pre-established receptor field. Two additional runs were completed using meteorological data collected over a one-year interval at the ABL burning ground. Complex terrain was also taken into account in the modeling evaluation. Additional details on the various aspects of the model evaluation are given in more detail below.

Limited on-site plume impact assessment for both off-site and on-site receptor sites was done during a one-week sampling period. Several combustion scenarios were monitored with air sampling equipment designed to collect selected plume species. Additional details concerning this effort are given at the conclusion of this section.

Source Term Data

The three burn scenarios were established using by the observed mass consumption or burn rate of the waste material which fall into high, medium and low rate categories. The three burn rates are intended to cover the range of burning conditions encountered at the burning ground under typical operating conditions. For each modeled event, the maximum allowable daily burn pan limit, discussed earlier in Section 2.3.3.3.2, was used in the source term calculations. Emission factors for the target analytes measured in the SNL chamber experiments were used along with the total burn mass and burn rate to estimate the mass release rate of the various target analytes selected for evaluation in the study. Plume release characteristics such as plume diameter, plume vertical velocity, plume temperature and the initial puff size in the high burn rate case, were estimated using observed conditions during actual burning ground operations as well as using test data from the SNL burn tests at the SWISH facility. Where uncertainties were encountered, estimates on the conservative side were selected as model inputs. For example, in cases of uncertain plume temperatures, estimates were made on the cooler side since a

cooler plume results in less buoyant puff or plume rise and will result in higher ground level concentrations in the model results.

Dispersion Models

A puff model was used to model the high burn rate case and a continuous release plume dispersion model was used to evaluate the medium and low burn rate conditions. A brief description of each of these models follows.

TRPUF Model

We used a gaussian puff model called TRPUF which was developed by Trinity Consultants for short term pollutant releases that are best described by a single puff. TRPUF is a gaussian puff model that is adapted from the EPA puff model and includes several enhancements the basic algorithms contained in the EPA PUFF model. Other features of the model are more fully described below.

Downwind Concentrations

TRPUF calculates downwind concentrations at each receptor for three distinct stability classes and reports results for all classes at a series of downwind distances ranging from 10 to 11,000 meters along with the maximum value encountered under any of the three general stability classes. The stability classes are unstable (Classes A, B and C), neutral (Class D) and stable (Classes E and F). Dispersion coefficients for each of the stability classes are user selectable and for these runs the Pasquill-Gifford tabulations were selected.

Initial Puff Description

The initial puff size can be described by specifying the initial puff size in horizontal and vertical one-sigma distances along with the downwind distance at which the puff is observed or by specifying the release amount and initial concentration of a particular pollutant in the puff.

Plume Rise

Three plume rise formulations are included in the TRPUF model however when no building downwash conditions are specified, as was in case in our modeling runs, only two of these are used to evaluate plume rise. One is Brigg's momentum plume rise and the other is Brigg's distance dependent buoyant plume rise. The first assumes that the plume goes to its highest point immediately above the release point and the second allows the plume to make a gradual ascent to its maximum height. The type of plume rise is dependent upon the stability class so that different rise algorithms may be used under different stability classes.

Building Downwash

The model includes provisions for the inclusion of building structures in the vicinity of the plume, however we do not discuss them in any detail here since the modeled release scenarios do not include structures in the immediate vicinity of the release point.

Model Output

Output data are available in both tabular and graphical format and both are used in the results presented in this report. In general we relied upon tabular data since these could easily be read for a number of downwind distances ranging from 10 to 11,000 meters from the release point.

Topography

Although the model is not specifically designed deal with complex terrain, the user does have the option of setting the receptor height at some level other the burn pan elevation. We used this capability to evaluate maximum 1-hour average concentrations at a range of receptor heights corresponding to the range of altitudes encountered in the region surrounding ABL. Additional details on this approach are given in the paragraphs dealing with model setup parameters and discussion of results.

ATDM Model

We used a gaussian puff model call the All Terrain Dispersion Model (ATDM) developed by Trinity Consultants to model continuous plume releases in the medium and slow burn rate cases. The ATDM model is a hybrid gaussian dispersion model that calculates concentrations from point, area, and volume source emissions in simple (receptor at or below stack height), intermediate (receptor above stack height and below stabilized plume center-line) and complex (receptor above stabilized plume center-line) terrain. The ATDM model uses plume dispersion algorithms contained in two EPA dispersion models, namely, ISCST2 and COMPLEX1. It also uses the algorithm in the POSTIT post-processor to calculate concentrations in intermediate terrain.

Terrain Designations

For receptors located in simple terrain, the ATDM model uses the ISCST2 algorithms to calculate downwind receptor site concentrations. Aerosol gravitational settling and deposition are disabled in this particular configuration however to provide a worst case evaluation. Receptors located in complex terrain are handled by the COMPLEX1 algorithm which incorporates various means to account for changes in plume height as the plume passes over topographical features. How the plume height is varied is determined by the meteorological stability class and the height of the plume above each receptor point for which a calculation is carried out. In the case of receptors falling in intermediate terrain, the ATDM model calculates receptor concentrations using both algorithms and selects the highest result for output.

Sources

The model can handle multiple sources, however, in this screening analysis, we have chosen to model the burning operations as a single point source. Additional details on receptor field designation, complex terrain input, and meteorological inputs are given in following sections. A complete description algorithms in the model can be found in the EPA users guide for the ISCST2 model [EPA, 1992].

Output

Output data from the model is available in both tabular and graphical format and both are used in the results presented in this report. Graphical data can be directly imported into a graphical software package so that concentration isopleths of the plume at the receptor field can be prepared.

Topography

As is evident from earlier discussions on terrain, the model accepts a receptor field in three-dimensional space so that topographical features can be taken into account in the plume dispersion calculations.

Building Effects

Like the TRPUF model, the ATDM model has the capability of dealing with wind wake effects from large structures in the vicinity of the source however, this capability was not necessary in these analyses since no large structures are encountered close enough to the burning ground to exert any wind flow pattern influence.

Meteorology

The model will accept a variety of meteorological inputs ranging from a standard screening meteorological data set to on-site hourly meteorological data. In these particular screening assessments the built-in screening meteorology file was used. The file contains a series of atmospheric stability categories and wind speeds that would be bracket meteorological conditions likely to be encountered at the site.

Topography Data

We downloaded topographical data for the United States Geological Survey CUMBERLAND map (No. 39078-A1) via the Internet from a USGS web site at the Earth Science Information Center at Reston, VA. These map data are 1:250,000 scale derived from a Digital Elevation Model and are packaged in 1 degree latitude by 2 degree longitude blocks for the entire continental US as well as Hawaii and Alaska. The basic digital elevation model is produced by the US Defense Mapping Agency using cartographic and photographic data sets. The horizontal resolution of these data are 3 arc-second or approximately 70 meters in longitude (at 39.5N degrees latitude which corresponds to the ABL location) and about 90 meters in latitude. Elevation data from the digital elevation model are given to the nearest meter. These data were first converted from latitude-longitude (WGS-1984 coordinate system) to UTM coordinates since the ATDM model works best in UTM coordinates. The data were then passed to SURFER®, which is a 3-D graphics data package, where additional interpolation was done to produce an appropriate grid density for use in the ATDM model.

Receptor Field Designation

The eastern portion of the receptor field for the region surrounding the ABL burning ground is schematically shown in Figure A-1. A mirror image was generated for the western half of the receptor field as well, however, these points are not shown in the figure. Eighteen radials were constructed starting at the center of the burning ground and projecting outward, starting at true north and progressing around the compass at 20 degree intervals. A receptor point was

selected every 135 meters along each of the radials for a total of 360 receptor points over the entire polar grid. These 18 radials were input into the 3-D graphics package along with the elevation grid obtained from the USGS. The altitude from the grid was then determined at each receptor point by cross comparison of these two data sets using algorithms in the software. In summary then, a receptor field was set up in polar coordinates with the grid center located at the center of the burning ground. The polar grid had a overall diameter of 5.4 km and contained 360 individual receptor points with a designated altitude to the nearest meter for each point. These data were then passed to the ATDM model and used as the receptor field for the various modeled scenarios.

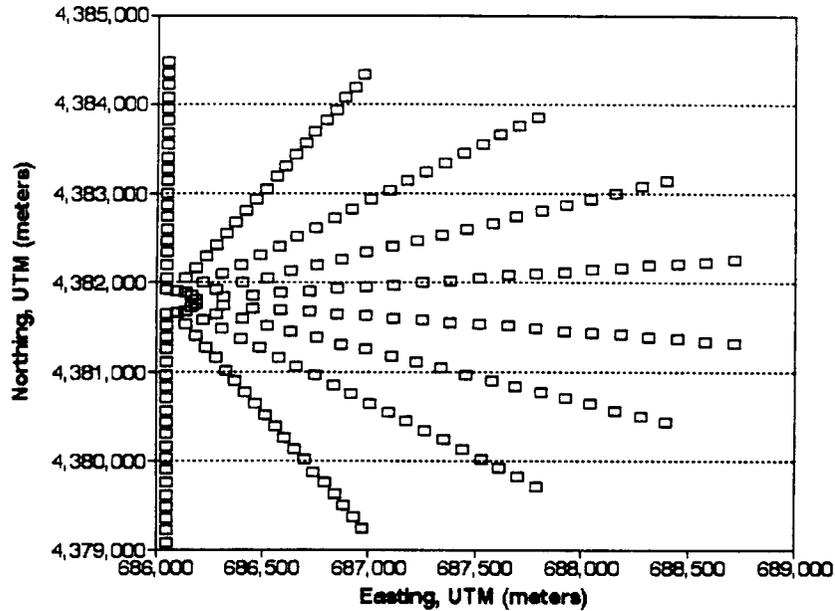


Figure A-1 A diagram of the eastern half of the receptor grid. Each square represents a receptor point. The western half of the receptor field, not shown, is a mirror image of the eastern half.

Meteorological Data

Three types of meteorological data were used in the modeling runs described in this section: (1) worst-case meteorology for puff dispersion; (2) Worst-case meteorology for continuous plume dispersion; and (3) On-site meteorological data collected near the ABL burning ground over a period of one-year with various meteorological instruments. The first two are further discussed in following sections that describe model inputs. A brief discussion of the on-site meteorological data follows:

On-site meteorological data was collected at the ABL burning ground during the period December 1994 through November 1995. In late November 1994, an

acoustic sounder was set up at the burning ground in order to develop winds speed and direction profiles in 15-minute intervals to assist in establishing burn criteria. In late February 1995, a 30-m meteorological tower was installed at the burning ground that included a full suite of meteorological sensors such as wind speed, wind direction, temperature, relative humidity, and solar intensity and other parameters. Data from these two systems were combined by Aerovironment Inc., under contract to the ABL facility, to produce a one-year meteorological data set at the 30-m level, for use the the ATDM air dispersion model. The data set included hourly averages of wind direction, wind speed, temperature, stability class (determined from multi-level temperature, and/or solar insolation measurements, and/or sodar data), and mixing height. Quality assurance procedures were carried out on these data sets by Aerovironment personnel prior to their release to Sandia for inclusion in modeling runs. Additional information on these data processing and quality assurance efforts is contained in a separate report currently in publication by Aerovironment.

Source Location for Model Input

For this screening analysis, the point of origin of the puff or plume was taken to be the center of the burning ground. Although the burning ground contains five functional burning pads, for this worst case screening analysis they were aggregated into a single location at the center of the burning ground. Using a common release point for all burn pits in the modeling effort adds a level of conservatism to the results since the use of multiple source locations would reduce plume impacts at any particular receptor location.

Puff and Plume Release Scenarios

Case No. 1 - High Burn Rate Puff Release - Screening Meteorology

For the high burn rate scenario we chose to model the combustion of the aluminized composite propellant using the TRPUF model that was described earlier. The model was run for a hydrogen chloride release since short term exposure hazards are most likely to be encountered from this pollutant species. The puff model does not explicitly deal with topography, however we carried out six model runs, changing only the receptor height in the input file, in order to estimate a range of ground level concentrations at various elevations above the source release elevation. Specific model inputs and assumptions are listed below:

Puff Dispersion Model: TRPUF, Trinity Consultants Inc.

Source Material: Aluminized Composite Propellant

Source Mass: 500 kg (One-half Total Daily Burn Pan Limit)

HCl Emission Factor: 0.21 (assumes all chlorine released as HCl)

HCl Release Mass: 105 kg

Burn Rate: 5 kg/s

Burn Duration: 100 s

Ambient Temperature: 20 C
Puff Dispersion Coefficients: Pasquill-Gifford
Initial Puff Diameter: 50 m
Initial Puff HCl Concentration: 1,150 ppmv
Release Height: 1 m
Release Velocity: 5 m/s
Release Temperature: 500 C
Release Plume Diameter: 5 m
Wind Speed: 1.5 m/s
Receptor Heights: 0, 10, 25, 50, 100 and 200 m above the burn pan elevation

Outputs from the model were instantaneous maximum and 1-hour average concentrations for HCl. Estimates of concentration levels for other target species were made using the product of the HCl results and the ratio of the emission factor for the species of interest to the emission factor for HCl.

Case No. 2 - Intermediate Burn Rate Continuous Release - Screening Meteorology

The intermediate case scenario involved a moderate burn rate of a pure energetic material with a lower surface area to mass ratio than encountered in the high burn rate case. For this scenario, we chose to model lead emissions from a lead-containing pure double base propellant burning at a rate of 200 g/s. This burn rate is typically what was observed during testing activities at the Sandia SWISH facility. The ATDM model was used to estimate worst case 1-hour average concentrations over the entire polar grid receptor field described earlier. An EPA-developed screening meteorology file built into the model was used for input meteorology. This file contains a wide range of wind speed and atmospheric stability class conditions which encompass any meteorological condition likely to be encountered on site. The model was run 18 different times with 20 degree changes in the wind direction in each successive run such that the range of topography surrounding the burning ground could be evaluated for plume impacts. Specific model inputs are listed below:

Plume Model: ATDM, Trinity Consultants Inc.

Source Material: Double Base Propellant

Source Mass: 500 kg (One-half Total Daily Burn Pan Limit)

Source Burn Rate: 200 g/s

Pb Emission Factor: 0.0088 (based on original formula -- assumes all lead released into plume)

Pb Release Rate: 1.8 g/s

Burn Duration: 40 min

Plume Temperature: 800K

Plume Diameter: 5 m
Plume Vertical Velocity: 5 m/s
Meteorology: EPA Meteorology Screening File
Wind Direction: Varied over 360 degree in 20 degree increments
Plume Dispersion Coefficients: Pasquill-Gifford
Dispersion Mode: Rural
Receptor Height: 1.7 m agl

Model outputs were 1-hour average lead concentrations at all receptor sites assuming a continuous plume release over the entire hour. The highest value in the receptor field was selected from the output list and used in further risk characterization procedures. Equivalent concentrations of other target species were determined by using the product of the lead concentration results at a given receptor and the ratio of the emission factor for the species of interest to the emission factor for lead.

Case No. 3 - Low Burn Rate Continuous Release - Screening Meteorology

The low burn rate case scenario is very similar to the intermediate burn rate case with several changes. In this case, a P/E-contaminated waste burn is assumed with a lower burn rate of 10 g/s. Carbon monoxide was selected as the species to be modeled since high CO emissions were measured during chamber testing of the P/E-contaminated mixtures. Meteorological inputs were the same as used for Case No. 2.

Plume Model: ATDM, Trinity Consultants Inc.
Source Material: P/E-contaminated Waste
Source Mass: 500 kg (two simultaneous 250 kg burns with co-mingled plumes)
Source Burn Rate: 10 g/s
CO Emission Factor: 0.35 g/g
CO Release Rate: 7 g/s
Burn Duration: 7 hr
Plume Temperature: 340K
Plume Diameter: 5 m
Plume Vertical Velocity: 1 m/s
Meteorology: EPA Meteorology Screening File
Wind Direction: Varied over 360 degree in 20 degree increments
Plume Dispersion Coefficients: Pasquill-Gifford
Dispersion Mode: Rural
Receptor Height: 1.7 m agl

Case No. 4 - Intermediate Burn Rate Continuous Release - On-site Meteorology

A second intermediate emission rate continuous release scenario involved a moderate burn rate of a pure energetic material with a lower surface area to mass ratio than encountered in the high burn rate case. For this modeling scenario, we used those emission properties outlined in Case 2, which were lead emissions from a lead-containing pure double base propellant burning at a rate of 200 g/s. The ATDM model was used to estimate worst case 1-hour average concentrations over the entire polar grid receptor field described earlier. The on-site meteorology file, containing hourly averages of wind speed, direction, temperature, atmospheric stability and mixing height, was used in this model run. Specific model inputs are listed below:

Plume Model: ATDM, Trinity Consultants Inc.

Source Material: Double Base Propellant

Source Mass: 500 kg (One-half Total Daily Burn Pan Limit)

Source Burn Rate: 200 g/s

Pb Emission Factor: 0.0088 (based on original formula -- assumes all lead released into plume)

Pb Release Rate: 1.8 g/s

Burn Duration: 40 min

Plume Temperature: 800K

Plume Diameter: 5 m

Plume Vertical Velocity: 5 m/s

Meteorology: On-site Meteorology File (0800 - 1600 hr averages only)

Plume Dispersion Coefficients: Pasquill-Gifford

Dispersion Mode: Rural

Receptor Height: 1.7 m agl

Model outputs were 1-hour average lead concentrations at all receptor sites assuming a continuous plume release over the entire hour. The highest value in the receptor field outside the plant boundary was selected from the output list and used in further risk characterization procedures. Equivalent concentrations of other target species were determined by using the product of the lead concentration results at a given receptor and the ratio of the emission factor for the species of interest to the emission factor for lead.

Case No. 5 - Low Burn Rate Continuous Release - On-site Meteorology

This low burn rate case scenario is the same as Case 3 with the exception that the on-site meteorological file was used in the model instead of the screening meteorology file. Specific model inputs are listed below.

Plume Model: ATDM, Trinity Consultants Inc.

Source Material: P/E-contaminated Waste
Source Mass: 500 kg (two simultaneous 250 kg burns with co-mingled plumes)
Source Burn Rate: 10 g/s
CO Emission Factor: 0.35 g/g
CO Release Rate: 7 g/s
Burn Duration: 7 hr
Plume Temperature: 340K
Plume Diameter: 5 m
Plume Vertical Velocity: 1 m/s
Meteorology: On-site Meteorology File (0800 - 1600 hr averages only)
Wind Direction: Varied over 360 degree in 20 degree increments
Plume Dispersion Coefficients: Pasquill-Gifford
Dispersion Mode: Rural
Receptor Height: 1.7 m agl

Modeling Results`

Case No. 1 - High Burn Rate Scenario - Screening Meteorology

Puff model results are shown graphically in Figure A-2 for the high burn rate case. Downwind 1-hour average HCl concentrations in units of ppmv are shown as a function of distance for a range of receptor heights. High levels in excess of 1 ppmv are observed for receptor heights of 0, 10 and 25 m however these values are observed at downwind distances less than 40 m from the release point and are within the burning ground which personnel are restricted from during burning operations. We compared the curves in Fig 6-2 with computer-generated slices through the topographical map on radials extending out from the burn site at 20 degree increments. A maximum off-site 1-hour average HCl exposure of 0.5 ppmv occurs at a receptor point approximately 2,225 m along a 60 degree radial from the burn site. This value was used in further hazard analysis for the high burn rate scenario.

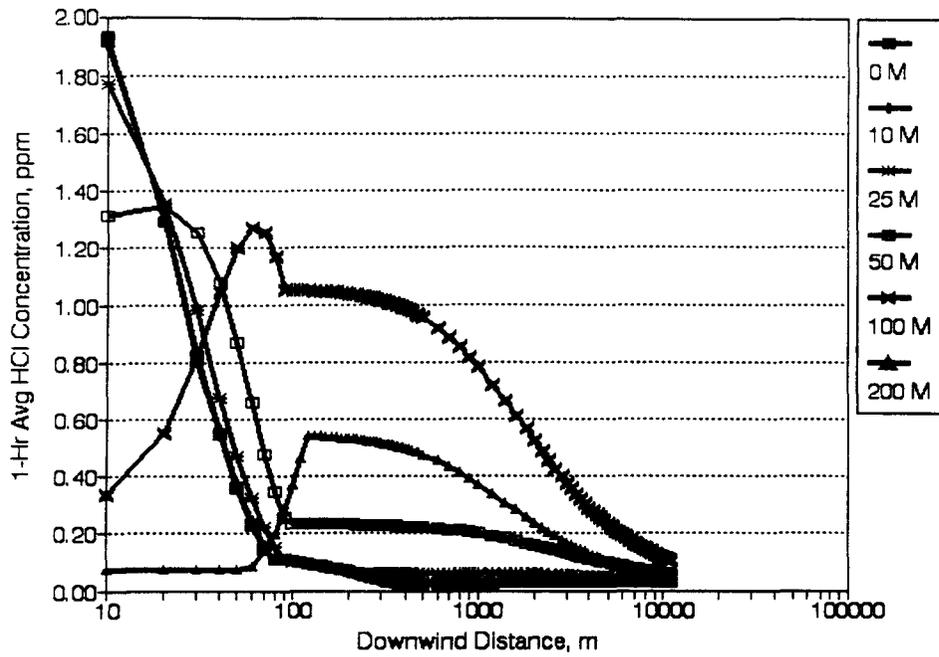


Figure A-2 One-hour average HCl concentrations as a function of downwind distance and receptor height for the high burn rate scenario

A similar plot scaled to show maximum instantaneous HCl values as a function of downwind distance and receptor height is shown in Figure A-4. A maximum instantaneous exposure level of 15 ppm is observed at the same receptor point where the 1-hour average exposure level of 0.5 ppm was encountered. These data are useful in the evaluation of acute HCl exposure hazards and will be further discussed in the Risk Characterization section of this report.

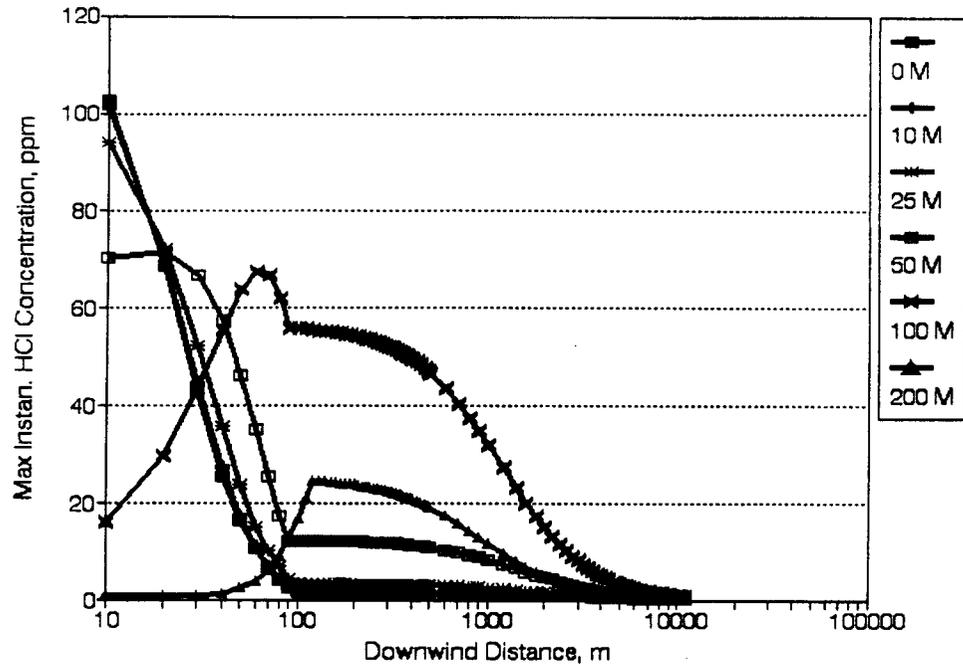


Figure A-3 Maximum instantaneous HCl concentrations as a function of downwind distance and receptor height for the high burn rate scenario.

Case No. 2 - Intermediate Burn Rate Scenario - Screening Meteorology

Results from the intermediate burn rate modeling scenario revealed high lead concentrations at several receptor points immediately south of the burning ground on plant property. Since these receptors were within plant boundaries, off-site receptors were obtained. An off-site maximum 1-hour average value of $1.18 \text{ ug/m}^3 \text{ Pb}$ was used in the following risk characterization efforts. This concentration level was observed numerous receptor points adjacent to the plant boundaries. Figure A-4 is a graphical display of typical results from the ATDM

run for the intermediate burn rate case showing concentration isopleths or areas of equal ground level lead concentrations. In this particular model run, the wind was blowing along the 80 degree radial, hence the plume impacts are observed in the northeasterly direction.

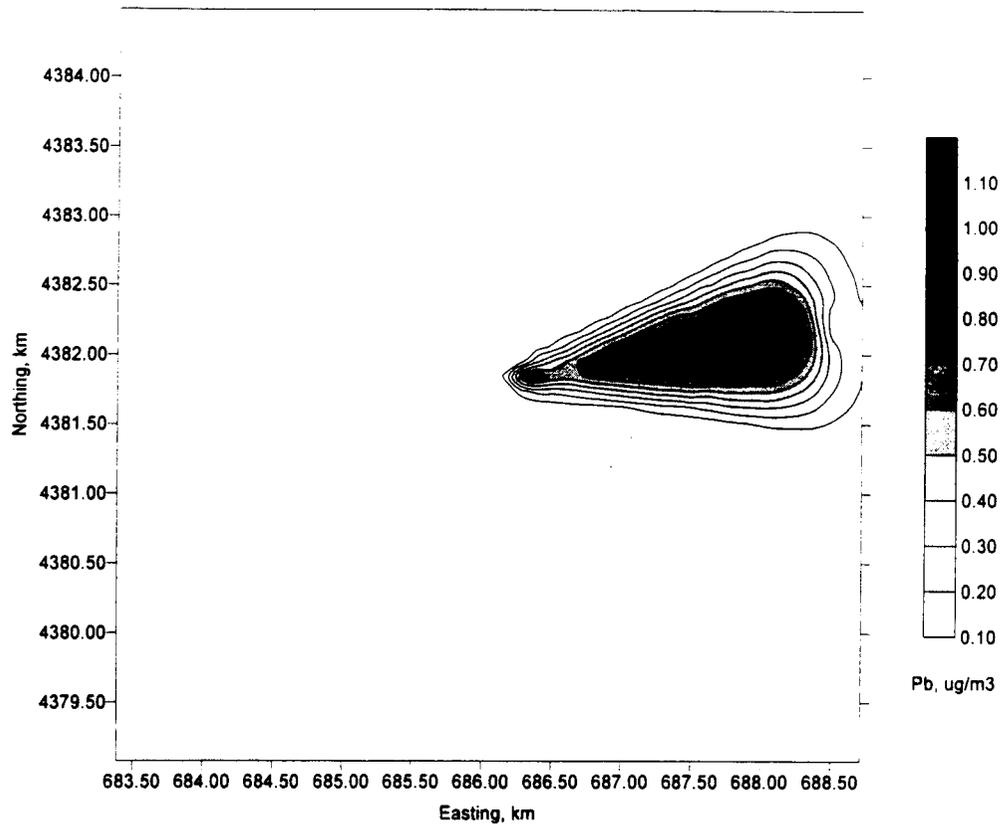


Figure A-4 A plot of expected worst case ground level lead concentrations during an intermediate burn rate with the wind blowing over the burning ground and along an 80 degree radial.

Case No. 3 - Low Burn Rate Scenario - Screening Meteorology

Results from the low burn rate case in which a CO release was modeled revealed the highest off site concentrations at receptor sites directly north of the burning ground along the 340 degree and 0 degree radials. The maximum hourly average CO concentration in these directions was 0.66 mg/m^3 . A typical concentration isopleth from the ATDM model runs of the low burn rate is shown

in Figure A-6. In this case, the wind is blowing from the south toward the north and the plume impacts can be observed directly north of the burning ground.

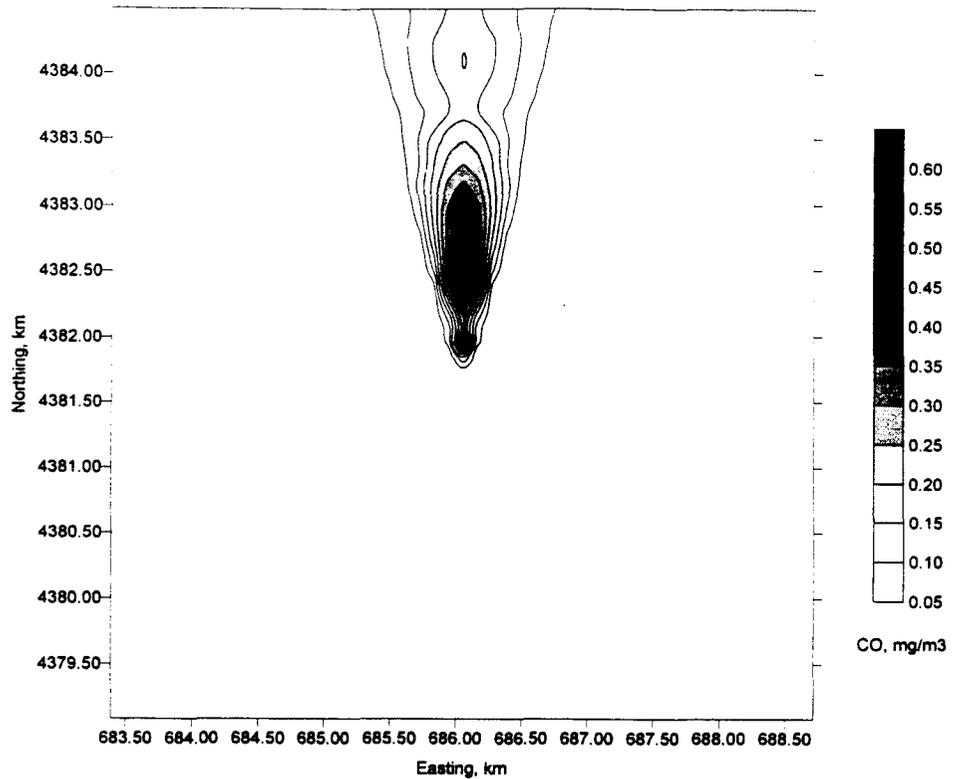


Figure A-5 A plot of expected worst case ground level CO concentrations during a low burn rate P/E-contaminated waste test. In this case the wind flow was from south to north

Case No. 4 - Intermediate Burn Rate Scenario - On-site Meteorology

Off-site plume impacts were evaluated by using Pb as a tracer compound in the model and calculating ground-level Pb concentrations for each hour of the year for which meteorological data were available. Expected plume concentrations were calculated and tabulated for each of the 360 receptor sites on the polar grid described earlier. Concentrations were also calculated at 36 receptor sites positioned at the intersection of the ABL plant boundary line and 36 radial lines extending outward from the center of the burning ground in 10 degree increments. The highest 1-hour average Pb concentrations are shown in Table A-2 for the plant boundary boundary receptors and all receptors in the polar grid.

Table A-1 A summary of highest 1-hour Pb concentrations from the intermeidate burn rate case and 1-hour CO concentrations using the ATDM model and on-site meteorological data.

Condition	1-Hr Average Pb Concentration (ug/m ³) @ UTM-East, UTM-North on YYMMDDHH	1-Hr Average CO Concentration (mg/m ³) @ UTM-East, UTM-North on YYMMDDHH
Highest Boundary Receptor	49.94 @687302, 4381057 on 95110217	0.93 @686050, 431864 95010618
Highest Off-Site Receptor	55.3 @686050, 4380429 on 95102617	0.70 @686050, 431864 95010618
Highest On-Site Receptor	64.4 @686050, 4380564 on 95102617	1.64 @686003, 4381653 on 95021408

Results for the highest off-site or boundary receptor from this particular analysis are about a factor of 5 higher than encountered in the same modeling effort using a screening meteorological file. The highest 1-hour average Pb concentration was 55.3 ug/m³, occuring at a receptor site directly south of the burning ground adjacent to the ABL boundary. The concentrations encountered over the entire receptor field for the hourly period that produced the highest off-site receptor concentration value are shown as concentration isopleths in Figure A-7.

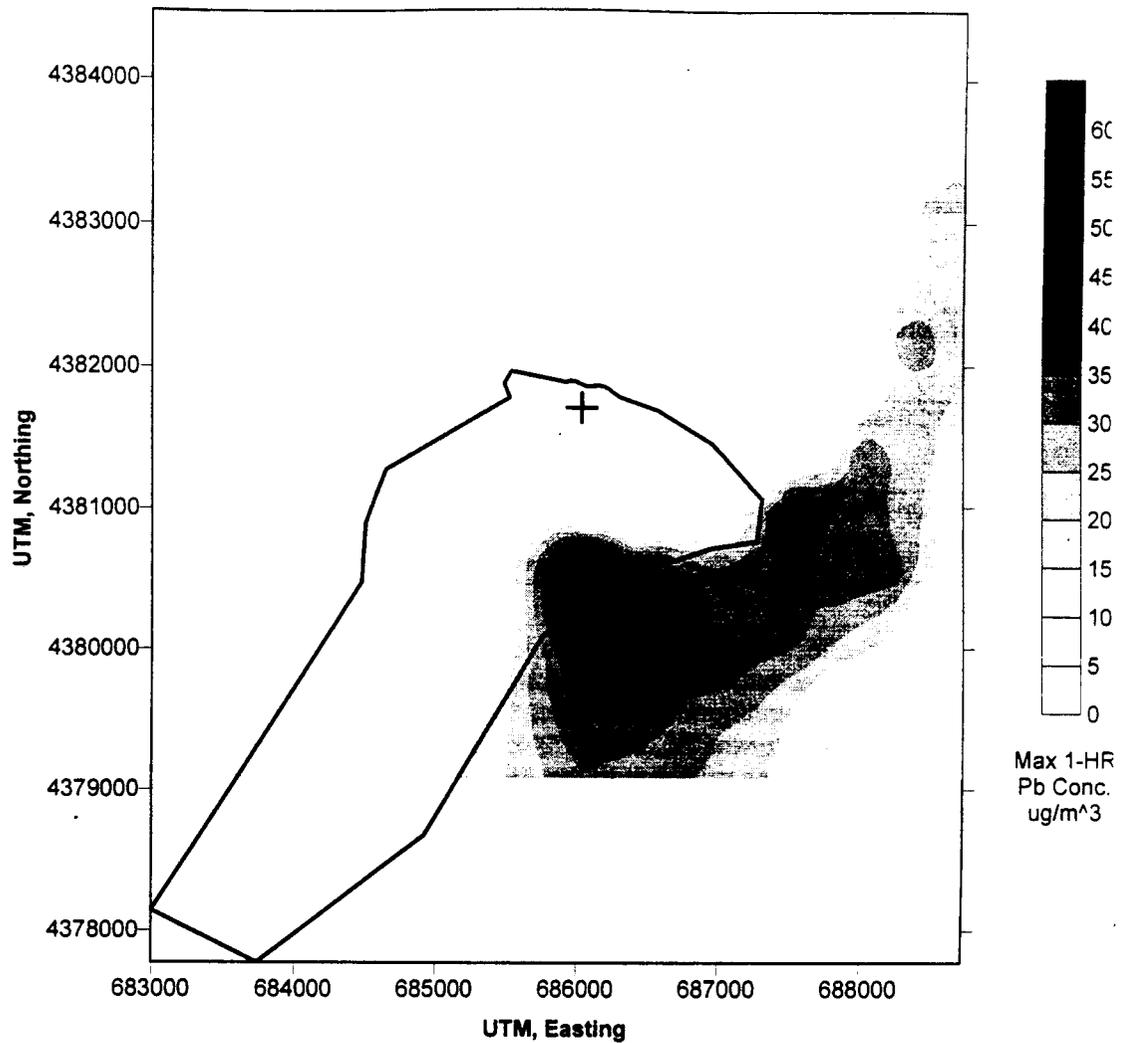


Figure A-6 A plot of expected worst case ground level 1-hour average lead concentrations during an intermediate burn rate model run using on-site meteorological data. The approximate ABL plant boundary is also shown in the figure as a solid line

Case No. 5 - Low Burn Rate Scenario - On-site Meteorology

Off-site plume impacts were evaluated by using CO as a tracer compound in the model and calculating ground-level CO concentrations for each hour of the year for which meteorological data were available. Expected plume concentrations were calculated and tabulated for each of the 360 receptor sites on the polar grid described earlier. Concentrations were also calculated at 36 receptor sites positioned at the intersection of

the ABL plant boundary line and 36 radial lines extending outward from the center of the burning ground in 10 degree increments. The highest 1-hour average CO concentrations are shown in Table A-1 for the plant boundary boundary receptors and all off-site receptors in the polar grid.

The low burn rate modeling analysis with on-site meteorology gave values that were about 40% higher than the screening case. The highest hourly CO levels encountered in the modeling run were inside the plant boundary in the immediate vicinity of the burning ground. The highest off-site hourly CO average was 0.93 mg/m³, occurring at a point about 750 m directly north of the burning ground. The concentrations encountered over the entire receptor field for the hourly period that produced the highest on-site receptor concentration value are shown as concentration isopleths in Figure A-8. Higher levels are also observed to the south of the burning ground however these are located on plant property and are not considered further.

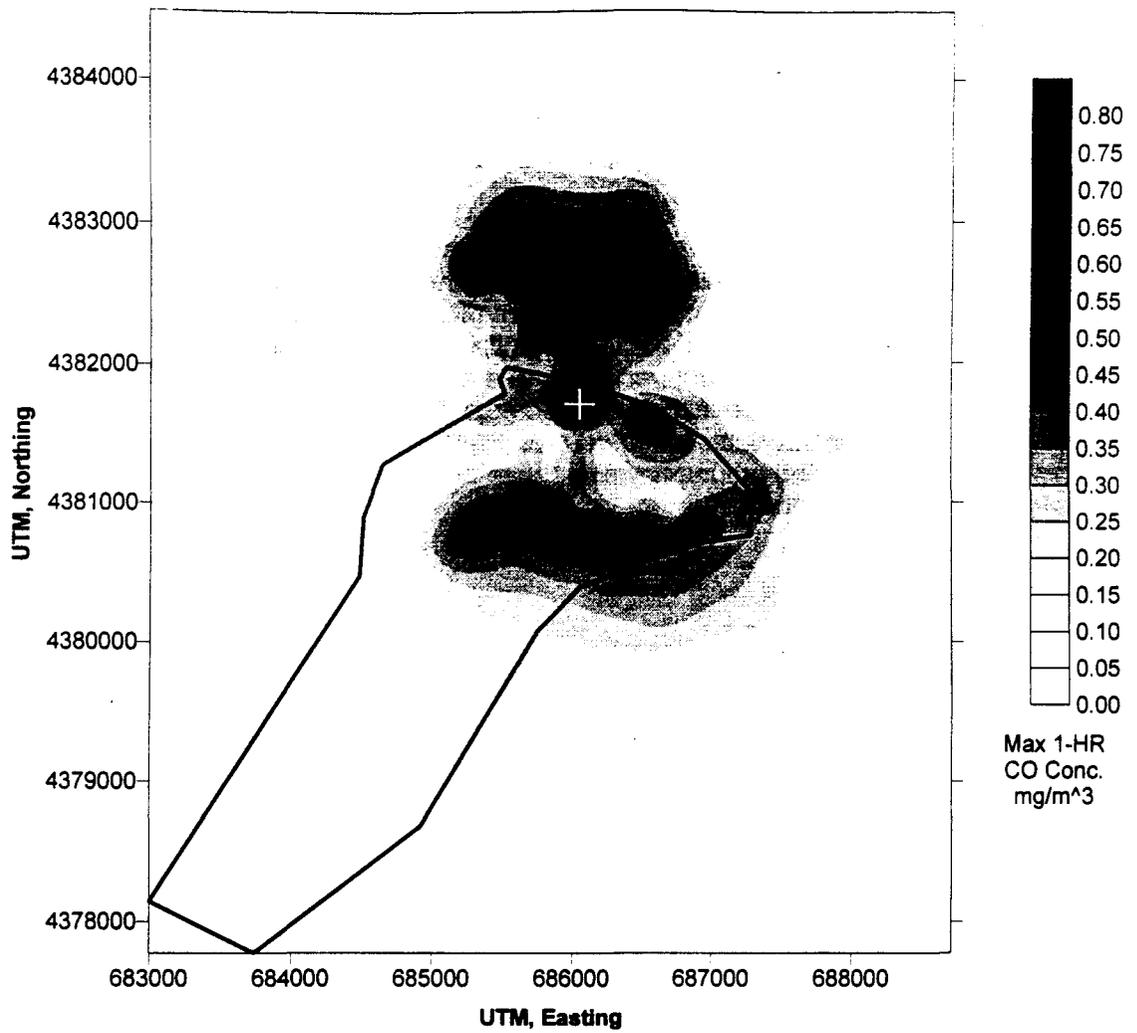


Figure A-7 A plot of expected worst case ground level 1-hour average CO concentrations during a intermediate burn rate model run using on-site meteorological data.