Air Assessment of Open Burning at Radford Army Ammunition Plant

by

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(ABSTRACT)

This project evaluates the characteristics of the open burning of NOSIH AA-2 sheet waste propellant at the Radford Army Ammunition Plant. The project considers the plume and burn characteristics, the removal of nitroglycerin from the waste, the emission of metals into the air, and the modeling of pollutant emissions from open burning.

The plumes generated from open burning fall well below the mixing heights. By burning at 2:30 PM and under Army regulations, the risk of inversions is essentially eliminated. The meteorological conditions influence the duration of the burns, and a dimensionless parameter is developed in this study to correlate the conditions to the burn duration.

Over 99 percent of the lead and copper in the propellant waste emits to the atmosphere. The removal efficiency of nitroglycerin in the propellant by open burning exceeds 99.9999 percent.

A worst-case analysis is conducted using the Trinity INPUFF™ model. Based on this conservative estimate, the concentrations of lead, copper, and NO_x compounds do not exceed the Short-Term Exposure Limits. However, the analysis exposes limitations in the model in the plume height calculations and the sampling time method.

Dedication

This paper is dedicated to my parents, Mr. and Mrs. H. Franklin Phipps. Without their encouragement, support, and belief in my abilities, I would have never accomplished this goal.

Acknowledgments

There are several people who played an integral role in the development and implementation of this research project. I would like to take the time to acknowledge their efforts.

I would first like to thank my advisor, Dr. J. Martin Hughes, for his support, encouragement, and creative suggestions. There were more than a few hours of brainstorming involved in this project, and Dr. Hughes made this time both enjoyable and productive. I would also like to thank the rest of my committee, Dr. Greg Boardman and Dr. John Little, for their valuable opinions and insight.

A special acknowledgment goes to Alliant Techsystems and the Radford Army Ammunition Plant personnel for their financial support and participation in the project. Mark Sullivan coordinated all of our work with the plant operations and allowed the project to run smoother than could ever be expected. A special thanks goes to Kaye Ayers, Fred Heim, Gerry McCarthy, and the personnel at the open burning ground for their time, effort, and patience.

Last but not least, the National Weather Service station in Blacksburg produced meteorological data that proved vital to the project.

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Introduction

The Radford Army Ammunition Plant (RFAAP) in Radford, VA generates several types of propellants for use by both military and commercial industries. Waste propellant is a hazardous waste due to its reactivity characteristic and is regulated under the Resource Conservation and Recovery Act (RCRA) [11].

The waste propellant is burned on-site by either a hazardous waste incinerator or open burning. The incinerator processes most of the waste; however, a portion of the waste generated cannot enter the feed system of the incinerator due to grit, pieces of metal, or other solid waste material. Consequently, open burning handles the remaining waste propellant.

This study deals with the characteristics of the open burning of NOSIH AA-2, a propellant produced at RFAAP. The study focuses on the following goals:

1. To determine removal for nitroglycerin, a Primary Organic Hazardous Constituent (POHC)used in RFAAP's incinerator permit.
2. To determine the air/ash mass ratio of metals in the propellant.
3. To determine the plume characteristics associated with the open-burning of NOSIH-AA2.
4. To model the emissions of metals and nitrogen oxide (NO_x) compounds from the open-burning of AA-2.

Background

Burning Ground Description

The open burning grounds at Radford Army Ammunition Plant is located along the New River, approximately 100-150 feet from the river edge. It consists of sixteen clay-lined pans, arranged in eight groups of two. The pans for each group are approximately 35 feet from each other, and the groups are separated by approximately 150 feet. The pans are located linearly along the river edge. Groundwater monitoring wells are located between the pans and the river edge to detect pollution.

The open-burning grounds office is located behind an earth and wood barricade. The office building is equipped with a 10m anemometer and temperature instrumentation. The ignition controls for remote ignition are located behind the barricade.

Open-Burning Pan Description

The cast-iron pans used for open burning are lined with clay. Each pan rests on cinder blocks at essentially ground level. Figure 1 illustrates the dimensions of the pan.

Each pan has a retractable cover to protect the clay and to help prevent erosion of the ash residue due to wind or rain. Figure 2 describes the cover design.

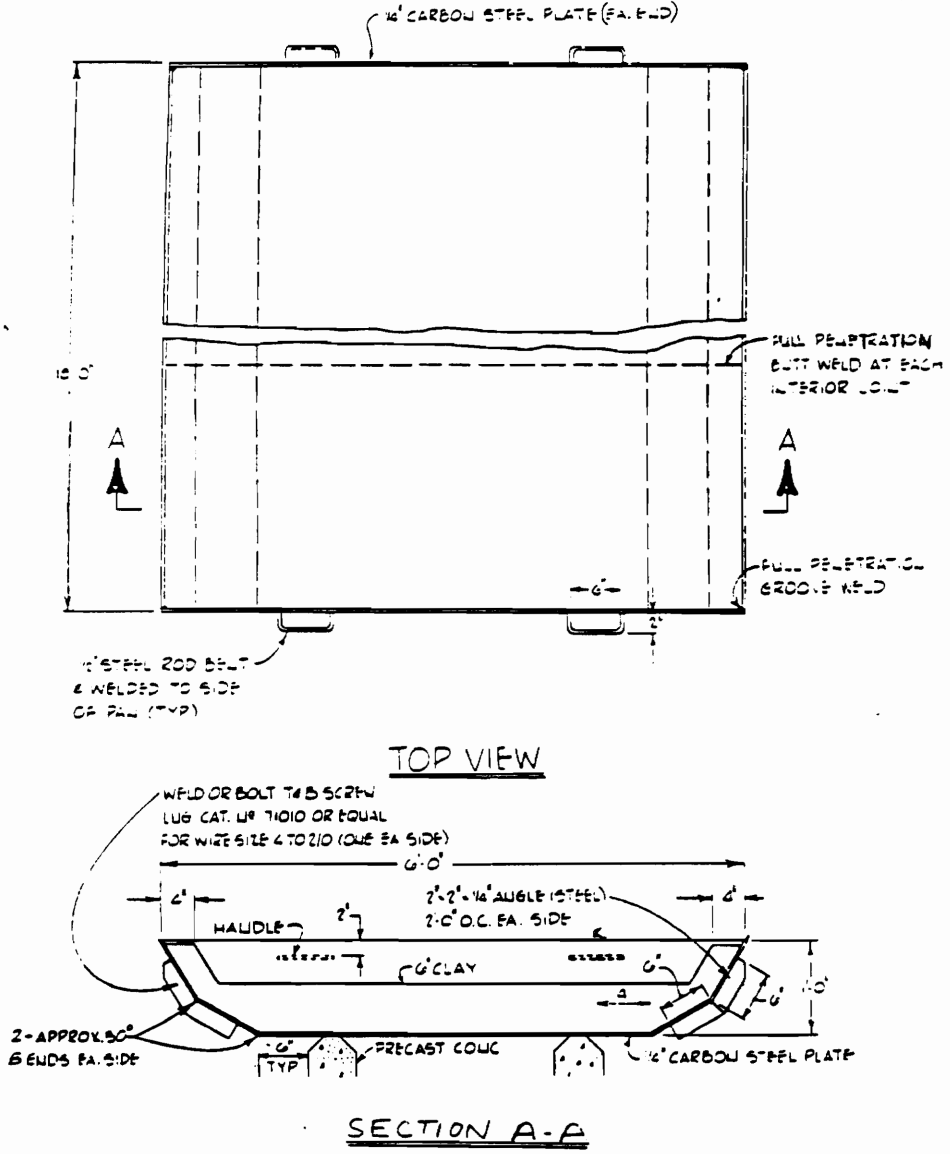


Figure 1. Open Burning Pan Dimensions

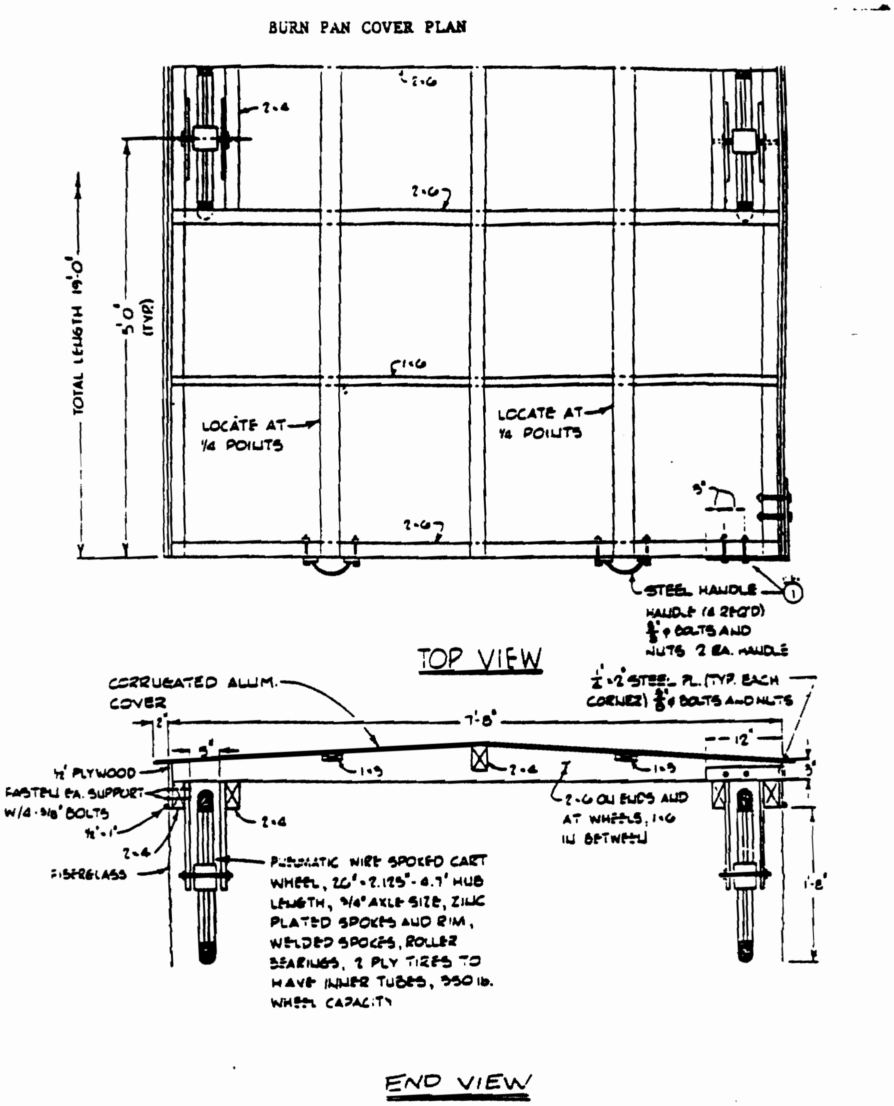


Figure 2. Open Burning Pan Cover Dimensions

Open Burning Procedures

- At approximately 9:00 AM, the decision to open burn is made based on current weather conditions and forecasts. Army regulations restrict the use of open-burning to wind speeds under fifteen miles per hour and non-overcast conditions.
- The propellant is placed on the pans. Once this is done, the propellant has to burned, regardless of conditions.
- The pans are armed with an ignition device and ignition propellant bags. The bags contain a propellant that burns hot enough to ignite the waste propellant.
- Approximately thirty minutes before the burn, scouts are placed along the river to spot any boats.
- Once the scouts report that the river is clear of boaters, an alarm sounds and a warning is announced over a loudspeaker stating that the open burning is about to commence.
- The pans are ignited remotely from behind the barricade. The pans are ignited one at a time, beginning with the pan farthest from the barricade. All personnel are required to be behind the barricade. The burns occur at 2:30 PM to prevent the occurrence of morning inversions. Army regulations restrict the burning to a total of eight pans per burn.
- The next morning, the pans are inspected to determine if any propellant ejected from the pans. The ash is cleaned from the pans, and samples are collected and tested using the Toxicity Characteristic Leaching Procedure (TCLP) test. Usually, the ash does not pass due to heavy metals such as lead and must be transported to a hazardous waste landfill.

Propellant Description

The nominal composition of NOSIH-AA2 is:

Nitrocellulose	51.0% (by weight)
Nitroglycerin	38.6%
2-Nitrodiphenylamine	2.0%
Di-normal-Propyl Adipate	1.6%
Triacetin	2.7%
LC-12-15 (mixture of 67% Lead Resorsilate 33% Copper Salysilate)	4.0%
Candililla Wax	0.1%

The final product is formed into sheets, which is later installed into rocket motors. The waste used in this study is generated from scrap shavings from cutting the sheets. The study utilizes this form of the waste in order to obtain a consistent waste composition.

Literature Review

Introduction

The military has been using open burning and open detonation for over fifty years to deactivate reactive compounds. Many of the compounds are too reactive for transport, so it is necessary for on-site treatment. Additionally, many facilities produce a variety of munitions which do not lend themselves to only one type of treatment, such as incineration. Consequently, open burning and open detonation are now widely used treatments for the controlled deactivation of reactive military components.

Open burning and open detonation will be required in the future because of the present reduction in military forces and the removal of obsolete munitions. According to Dr. William Mitchell [8], the current stockpile of propellants, explosive, and pyrotechnics is over 500,000 tons, with 220,000 tons expected to be added in fiscal year 1996. At the current standards, the Department of Defense can destroy 60,000-70,000 tons annually. Based on these figures, open burning and open detonation may continue to be an integral component of hazardous waste management within the military.

RCRA Subpart X Permitting

In 1988, Congress promulgated legislation requiring the issuance of permits to miscellaneous hazardous waste units under Subpart X of the Resource Conservation and Recovery Act (RCRA). Miscellaneous units comprise hazardous waste facilities and unit operations that cannot be characterized under the present RCRA permitted operations. Examples of miscellaneous units include shredders, carbon regeneration units and sludge dryers not designated as wastewater treatment units, mines, and open burning/open detonation units.

A difficult problem with open burning/open detonation permitting is the characterization of the waste treated and determining if the waste indeed falls under RCRA Subpart X regulation due to reactivity. According to Tope et al.[12], most propellants, explosives, and pyrotechnics (PEPs) are hazardous wastes due to exhibiting reactivity and/or toxicity characteristics due to heavy metals. Fleming et al. [5] defined the reactivity characteristic for RCRA Subpart X as follows:

"The methodology used for reactivity determination must meet the following requirements:

1) Ensure safety of operating personnel and the public from explosive hazards.
2) Ensure that all wastes that can be safely treated by a means other than open burning are so treated.
3) Conform to all requirements of the existing Department of Transportation (DOT) regulations for waste shipment.
4) Ensure that the waste will not react during storage and/or handling to form explosive precipitates or mixtures."

Based on these criteria, the following decision tree was developed for Picatinny Arsenal in New Jersey [5]:

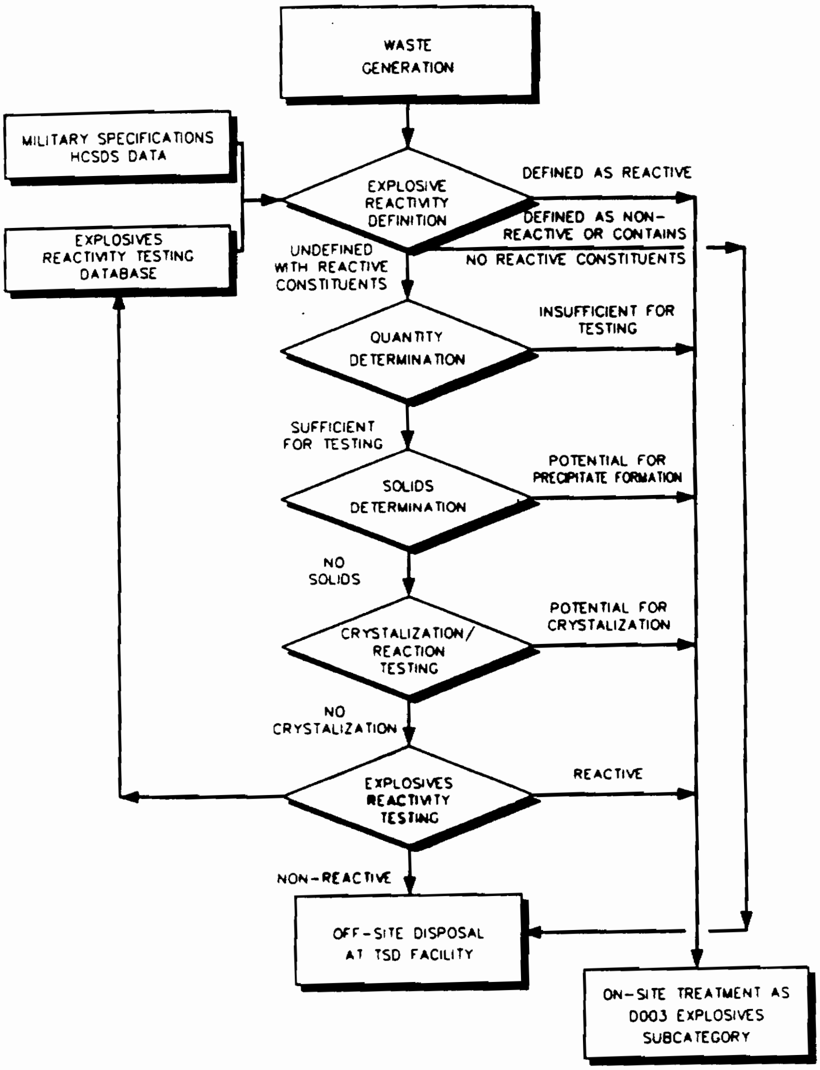


Figure 3. Explosive Reactivity Determination Decision Tree

(taken from Fleming et al., "RCRA Reactivity Definition for Energetic Wastes Treated by Open-Burning at Picatinny Arsenal, New Jersey")

Bangbox Testing at Dugway Proving Ground, Utah

In anticipation of emissions data required for Subpart X permits, the US Army developed a testing facility at Dugway Proving Ground in Utah to monitor and characterize open burning and open detonation [12]. Called the Bangbox, the facility consists of a 1000 cubic meter hemisphere made of an expandable material that can withstand the shock wave of detonations. The structure is continually ventilated, has climate control, and contains a suppressive shield to protect the hemisphere from shrapnel and debris. Figure 4 illustrates the layout of the facility [12].

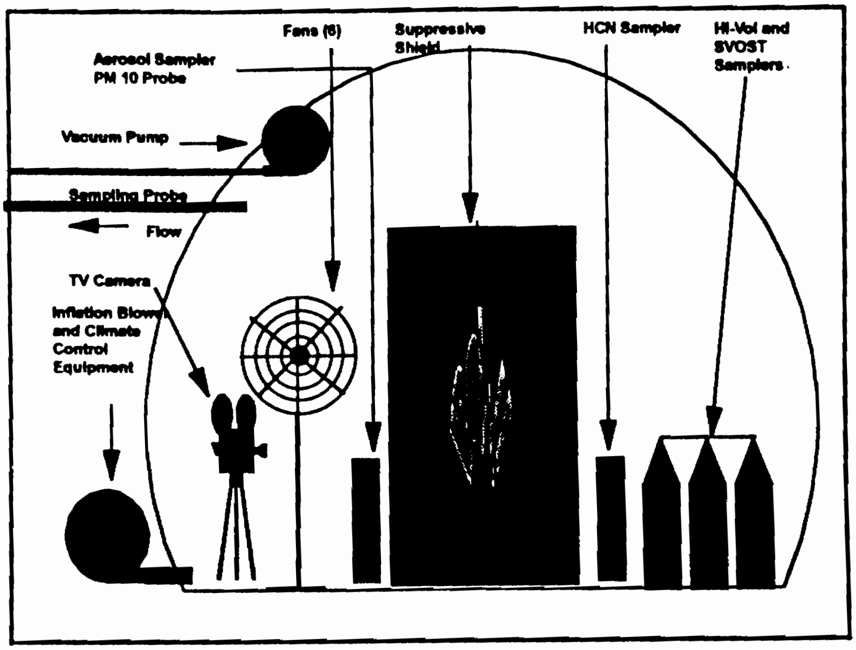


Figure 4. Diagram of Bangbox Equipment and Instrument Array

(taken from Tope et al., " The Environmental Acceptability of Open-Burning/Open Detonation")

Currently, the facility can test up to five pounds of propellant or explosive at one time. From this data, emission factors are calculated for pollutants of interest.

Air Dispersion Modeling for RCRA Subpart X Permitting

Air dispersion models predict effects of open burning emissions on ground level receptors. Stoner et al. [11] recommend the use of the INPUFF model for burns of less than one hour. INPUFF allows changing meteorological conditions and intermittent puff releases. This model serves as one criteria for writing permit documents for this type of waste facility.

A protocol was developed for RCRA Subpart X air dispersion modeling by Stoner et al. [11] which includes:

- Assume all metals are emitted completely. The Destruction and Removal Efficiency (DRE) is 0 for this case.
- Assume the total quantity of contaminants is released within a 1-minute period.
- Buoyancy-induced dispersion should be included in the model. This option takes into account the fact that the puff diameter is increasing as it rises, causing larger concentrations near ground level sources.
- The exit gas temperature can be approximated using several methods. Combustion modeling with programs such as POLU-13, developed by the Navy, can be used. The RCRA Subpart X checklist has a listed temperature of 3700°K, but the basis for this number is not clear.

An important parameter that must be estimated to use the model is the exit gas velocity. Lucas and Bentley [7] recommend videotaping the burn to estimate the velocity. A reference distance, such as the side of the burn pan, can be measured in the field for scaling to the videotape. From this reference distance, the velocity is calculated at the tip of the flame on the videotape with a stopwatch. Typical values of the exit velocity reported by Lucas and Bentley are 6 m/s for propellants and 3 m/s for wastes that require supplemental fuel [7].

Using the protocol and techniques, open burning can be modeled to determine ground-level receptor exposures. Risk assessments can then be evaluated to determine the environmental impact of open burning.

Experimental Methods

The major steps involved in the experimental sequence in order of their occurrence consist of the following:

1. Background Clay Sample Collection
2. Waste Propellant Sample Collection
3. Meteorological Data Collection
4. Adiabatic Flame Temperature Calculation
5. Filming the Open Burn
6. Ash Residue Sample Collection
7. Velocity Profile Analysis
8. Sample Analysis
9. Mass Balance for Metals
10. Air Dispersion Modeling

The study evaluates seven burns using NOSIH AA-2 propellant, from September 12-October 31, 1996.

1. Background Clay Sample Collection

A composite sample of clay is collected from the burn pans before each burn. The study utilizes the sample for background concentrations of lead, copper, and nitroglycerin. For the first burn, fresh clay is used so that any analyte concentration inherent to the clay would be identified and quantified.

The sample area of interest covers one-third the area of the pan. Figure 5 illustrates the area tested. The area is based on the large amount of sample that has to be collected for the ash sample, which will be discussed later.

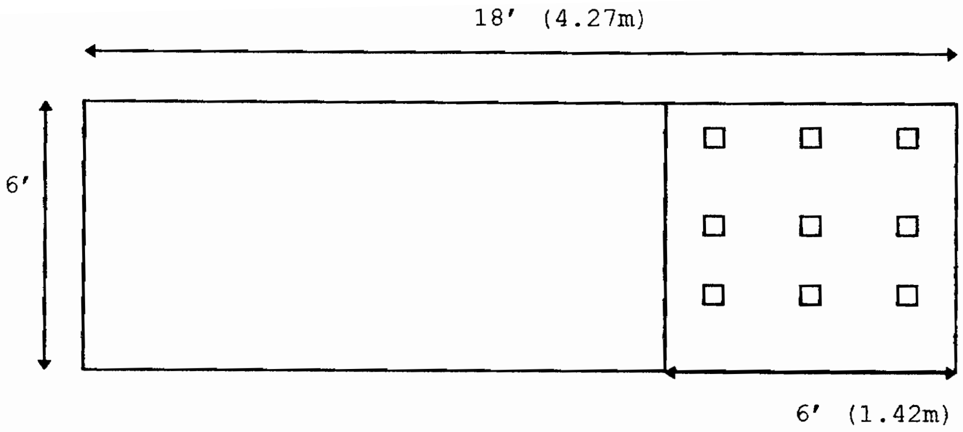


Figure 5. Sample Collection Area for Background Clay and Ash Residue Samples

A wire brush loosens the clay surface, and the samples are collected in a polyethylene (PE) sample bag. This bag is a standard bag used by the analytical department at RFAAP. Each bag is sealed with tape and transported to the analytical lab for storage.

2. Waste Propellant Sampling

A composite sample of the waste propellant is collected before each burn. Each container of propellant is weighed at the storage facility, and a sample of waste propellant is collected from each container. The composite sample is placed in a PE sample bag and sealed with tape for transport to the analytical lab.

3. Meteorological Data Collection

The study utilizes on-site measurements and data collected from the National Weather Bureau station in Blacksburg, VA. The 10-meter wind speed and ambient temperature are recorded on-site at the Burning Grounds Office. A sling psychrometer estimates the wet and dry bulb temperatures. The two temperatures and a psychrometric chart determine the amount of moisture in the air.

Weather balloon data from the National Weather Service station characterizes the mixing height level. The study uses the 7:00 PM balloon release data on the day of the burns. The intersection of the balloon data and the dry adiabatic lapse rate of -9.8°C/1000m determines the mixing height. Holtzman [6] recommends using the ambient temperature as the ground level surface temperature for afternoon releases over rural terrain.

4. Adiabatic Flame Temperature Calculations

An adiabatic flame temperature model is developed to estimate the initial plume temperature. Using the ambient temperature and the air moisture content, the model estimates the flame temperature for each burn. Refer to Appendix A for a description of the adiabatic flame temperature calculations.

5. Open Burn Filming

Each of the burns is recorded on videotape for plume velocity analysis. The videotaping is conducted remotely for safety considerations. The video camera is placed perpendicular to the length of the burn pan. A fully-charged battery is placed in the video recorder prior to each burn. The video camera is activated when the warning alarm was initiated, approximately five minutes before the burn. The recording is stopped once the coordinator determines it is safe.

6. Ash Sample Collection

The morning following the burn, a total ash sample is collected over the same pan area as the background samples (refer to Figure 5). The ash, which is seared to the clay itself, is loosened with a steel brush. All of the ash is collected until none is visible over the sampling area. The ash is collected in one sample collection bag and taken to the analytical lab, where it is weighed with an analytical balance and stored until it is analyzed. Because the balance used to weigh the sample can only handle a maximum of 10 pound, one-third of the pan area is collected to minimize errors and reduce the risk of sample loss.

7. Velocity Profile Analysis

For each burn plume, a velocity profile is compiled using the burn videotape. Either the distance between two vertical poles (3.51m) or the length of the burn pan (4.27m) serves as reference distances, depending on whether the brush blocks the camera's view of the pan. The reference distance is marked on a sheet of paper from the television screen.

Multiple reference distances compose the vertical scale for the velocity profile. The paper is taped to the screen vertically, with the point of plume generation being the base. The plume is timed using a stopwatch between each of the reference distances. Ten replicate time tests were conducted for each reference distance.

Additionally, each of the burns is timed for burn duration, from the point of first flame generation until the point of flameout. Ten replicate tests are conducted for each burn recording.

8. Sample Analysis

The analytical department at RFAAP conducts the sample analysis for each of the burns. The tests determine nitroglycerin, lead, copper, and moisture composition for all of the background, ash, and propellant samples. The analytical department stores all of the samples until after the final burn so that the analysis could be done in one batch.

The determination of nitroglycerin for the propellant utilizes one gram samples. The sample is extracted using the Soxhlet method and quantified using high performance liquid chromatography (HPLC). Ten gram amounts of ash and clay comprise the samples for their respective nitroglycerin amounts.

The lead and copper analysis utilizes nitric acid digestion and Atomic Absorption spectroscopy. All of the samples are digested using eighty (80) ml of nitric acid for forty-eight (48) hours. The samples are then diluted to 100 ml with water and analyzed.

The moisture content analysis utilizes two methods. For the ash and clay samples, 15 gram samples are weighed and placed in a vacuum oven at 45 degrees Celcius (°C) for 12 hours. The samples are weighed again to determine the amount of moisture loss. Since the propellant moisture content is very low, gas chromatography is utilized.

9. Mass Balance for Metals

Using the analytical data, a mass balance is performed to determine the amount of metals that remain in the ash and the amount that is emitted into the air. The collected ash sample contains both clay and ash. To separate the two, the following equations for the balance are used:

$$M_{ash}\ (X_{ash}) + M_{clay}\ (X_{clay}) = M_{comp}\ (X_{comp} - X_{back}) \qquad (1)$$

$$M_{ash} + M_{clay} = M_{comp} \qquad (2)$$

Mash = Mass of ash
Xash = Weight fraction of metal in the ash
Mclay = Mass of clay
Xclay = Weight fraction of metal in the clay
Mcomp = Mass of composite ash/clay sample
Xcomp = Weight fraction of metal in the composite ash/clay sample
Xback = Weight fraction of background clay

The weight fraction of metals in the ash, X_{ash}, is estimated using the value of the metals content in the propellant product, which was described previously. This value is used in the Waste Analysis Plan (WAP) for the incinerator permit for metals analysis. The other values are determined directly from the sample analysis. This leaves two equations and two unknowns, M_{ash} and M_{clay}. Once these values have been established, an overall materials balance is utilized to determine the air/ash metals ratio.

10. Air Dispersion Modeling

Using the data generated from each of the burns, a worst case analysis is conducted utilizing the INPUFF™ model from Trinity Software and meteorological and plume velocity data. Refer to Appendix B for the analysis description and results.

Results

Meteorological Conditions

Table I summarizes the meteorological conditions for the test burns. The dry and wet bulb temperatures determine the air moisture by utilizing the sling psychrometer and psychrometric chart. The ground level lapse rate is estimated using the first two to three readings from the weather station balloon data. The intersection of the balloon data with the dry adiabatic lapse rate line determines the mixing height for each burn. The stability class is a function of the wind speed and the solar insolation. Refer to Appendix C through I for a complete description of the meteorological data for each test burn.

Table I. Meteorological Conditions for Open Burns

Burn #	Temp (°C)	10-m Wind Speed (m/s)	Air Moisture (lb H2O/lb DA)	Ground Level Lapse Rate (°C/m)	Mixing Height (m)	Stability Class
1	26.1	1.5	0.0145	-0.00934	1650	A
2	22.2	3.1	0.0155	-0.00744	1150	B
3	16.7	0.0	0.0120	-0.00439	280	D
4	18.9	2.7	0.0120	-0.00288	900	C
5	15.0	1.6	0.0080	-0.00680	1650	B
6	17.8	0.0	0.0080	-0.00727	1150	A
7	20.0	5.1	0.0070	-0.00792	1100	C

Burn Characteristics

Table II illustrates the characteristics of the open burns. The burn duration is timed from ignition until complete flameout. The vertical velocity is based on timing the plume between a reference distance at different heights. The burn durations and the velocities are tested ten times per burn using the videotape. The height of maximum plume velocity is determined by plotting the vertical plume velocity versus the height above the burn pan and locating the maximum. Refer to Appendix C through I for the complete analysis.

Vertical plume velocities are not available for Burns #1 and #7. The video camera was too close to the pan to record the plume for Burn 1. For Burn #7, an attempt was made to estimate the final plume height by raising the camera height. The wind carried the plume directly toward the camera and was so strong that estimations of the plume height and velocity were impossible.

Table II. Open Burn Characteristics

Burn #	Propellant Weight (lb)	Burn Duration (s)	Maximum Vertical Plume Velocity (m/s)	Height of Maximum Plume Velocity (m)
1	420.5	13.71	NA	NA
2	427	16.18	6.6	17.5
3	371.5	19.32	6.9	9
4	421	19.15	8.5	18
5	424	16.39	7.1	9.5
6	431.5	17.31	8.1	23.5

The meteorological conditions have a direct effect on the burn duration. A dimensionless correlation parameter is defined for this study, called the burn duration parameter:

$$P_{BD} = -H_m * L_{gr} * M / T_{amb} \qquad (3)$$

P_{BD} = Burn Duration Parameter, dimensionless
H_m = Mixing Height, m
L_{gr} = Ground Level Lapse Rate, °C/m
M = Specific Moisture Content, dimensionless
T_{amb} = Ambient Temperature, °C

Table III summarizes the burn duration parameter for Burns 1-6. Figure 6 illustrates the relationship between the dimensionless parameter and the burn duration.

Table III. Burn Duration Parameter Summary

Burn #	Mixing Height (m)	Ground Level Lapse Rate (°C/m)	Ambient Temp. (°C)	Moisture Content (lb/lb)	Burn Duration Parameter	Burn Duration (s)
1	1650	-0.00934	26.1	0.0145	0.0085617	13.7
2	1150	-0.00744	22.2	0.0155	0.0059738	16.2
3	280	-0.00439	16.7	0.0120	0.0008833	19.3
4	900	-0.00288	18.9	0.0120	0.0016457	19.2
5	1650	-0.00680	15.0	0.0080	0.005984	16.4
6	1150	-0.00727	17.8	0.0080	0.0037575	17.3

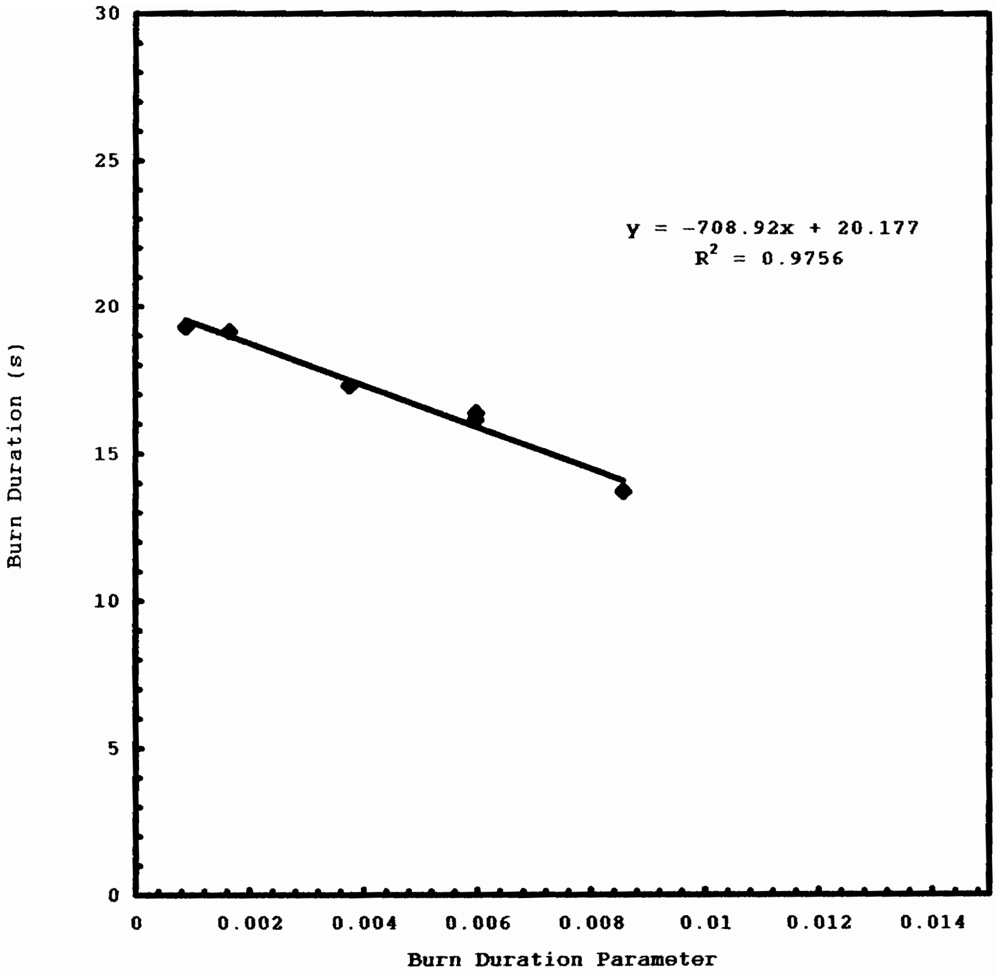


Figure 6. Burn Duration Versus Burn Duration Parameter

Note: The analysis uses 370-420 lbs of NOSIH AA-2 propellant.

Analytical Data

Tables IV and V summarize the analytical data for the open burn study. Table IV describes the ash and background clay samples, while Table V summarizes the waste propellant compositions. The weight fractions of the components in the waste propellant are consistent with the finished product (38.6 percent nitroglycerin, 1.54 percent lead, and 0.4 percent copper). The moisture for the propellant product is a maximum 0.6 percent by weight.

The moisture content in the clay decreases exponentially over the test period, from 22 percent (by weight) to less than 1 percent. Figure 7 illustrates the clay moisture content change.

The background sample for Burn #5 is not available. The propellant was put on the pad before the sample could be taken.

Table IV. Analytical Data for Ash and Background Clay Samples

	Burn #1 Background	Burn #1 Ash	Burn #2 Background	Burn #2 Ash	Burn #3 Background	Burn #3 Ash
NG (wt %)	<.005	0.005	<.005	<.005	<.005	<.005
Pb (wt%)	0.0011	0.1800	0.0530	0.0220	0.0960	0.0250
Cu (wt %)	0.0020	0.0700	0.0170	0.0080	0.0310	0.0080
H2O (wt%)	22.20	22.16	15.86	7.88	4.26	4.00

	Burn #4 Background	Burn #4 Ash	Burn #5 Ash	Burn #6 Background	Burn #6 Ash
NG (wt %)	<.005	<.005	<.005	<.005	<.005
Pb (wt%)	0.0360	0.0240	0.0400	0.0340	0.0330
Cu (wt %)	0.0070	0.0050	0.0090	0.0080	0.0090
H2O (wt%)	3.23	2.00	1.44	1.02	2.49

	Burn #7 Background	Burn #7 Ash
NG (wt %)	<.005	0.01
Pb (wt%)	0.0370	0.0610
Cu (wt %)	0.0090	0.0090
H2O (wt%)	0.84	0.97

Table V. Analytical Data for Propellant Waste

Burn #	1	2	3	4	5	6	7
NG (wt %)	36.50	37.90	36.50	37.10	36.30	35.80	36.50
Pb (wt%)	1.55	1.27	1.48	1.43	1.40	1.43	1.23
Cu (wt %)	0.41	0.42	0.40	0.43	0.42	0.41	0.38
H2O (wt %)	0.39	0.39	0.30	0.48	0.39	0.37	0.37

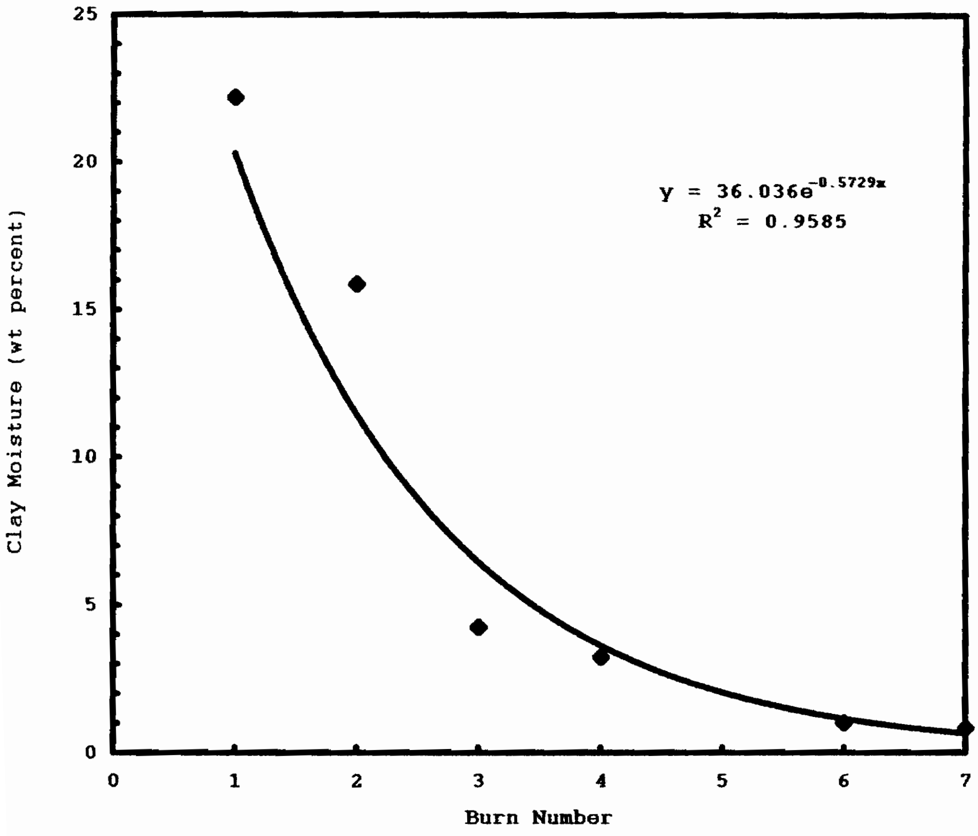


Figure 7. Clay Moisture from Open Burn Pan

Adiabatic Flame Temperature

Utilizing the meteorological conditions and moisture content in the waste propellant, the adiabatic flame temperatures are estimated to be between 1546-1552°C.

Air/Ash Emissions Ratio for Metals

In several cases with the background and the ash samples, the weight fraction of metals in the background is actually higher than the ash sample (Refer to Table IV.). Using the Shapiro/Wilkes statistical test for normal distributions and a paired t-test, there is no statistical difference between the background and ash samples for lead or copper over the data set as a whole. To estimate the air/ash ratio, the lead and copper mass balances for the first burn are used. Based on this analysis, over 99 percent of the metals in the propellant waste go to the air. Table VI presents the results.

Table VI. Metals Mass Balance for Burn #1

COPPER

Mcomp :	1427.5 gm
Xcomp:	0.0007
Xash:	0.0041
Xclay	0.00002
Xback:	0.00002

Mash:	230.8 gm
Mclay:	1196.7 gm

LEAD

Mcomp:	1427.5 gm
Xcomp:	0.0018
Xash:	0.0155
Xclay	0.000011
Xback:	0.000011

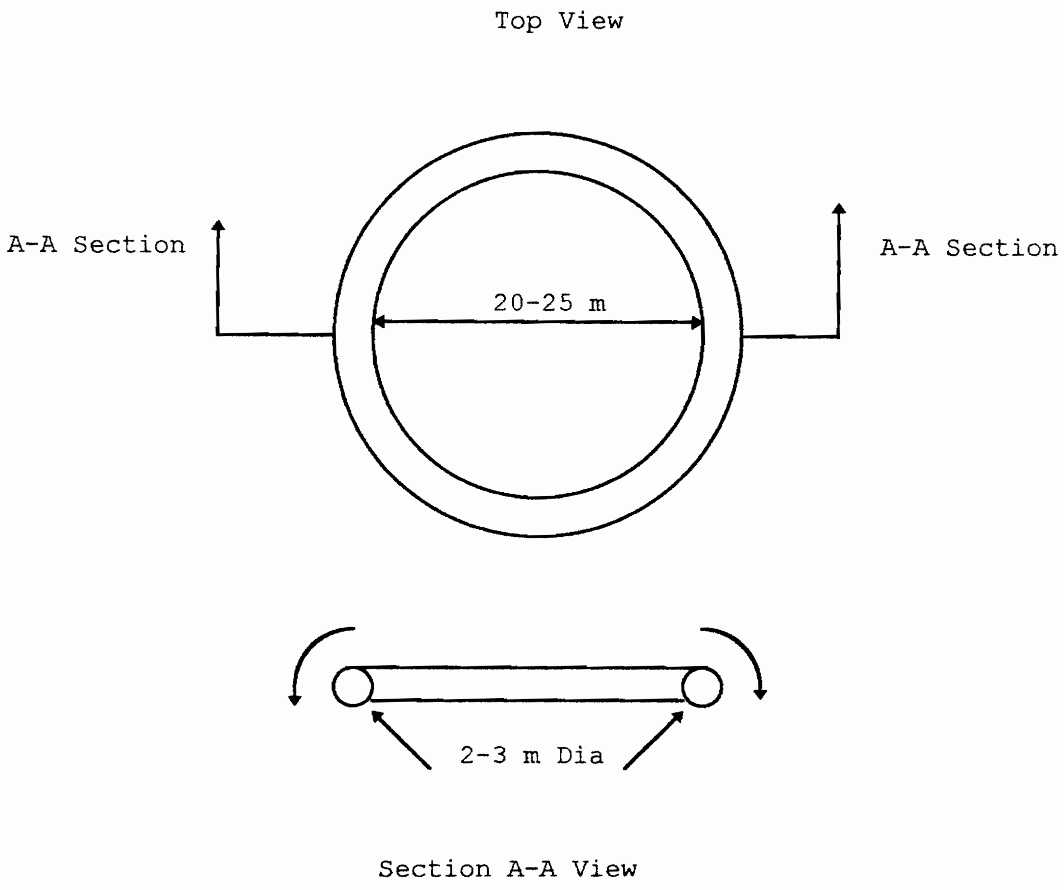
Mash:	163.8 gm
Mclay:	1263.7 gm

Average Mash:	197.3	gm
Mash for Entire Pan:	591.9	gm
	1.3	lb

Lb Ash/1000 Lb Waste:	3.1	
Air/Ash Ratio:	321.9	lb air/lb ash
% Emitted to Air:	99.7	%

Smoke Ring Effect

On two occasions, Burns #3 and #6, the plume took on the shape of a smoke ring. The white ring stayed in place for 3 to 5 minutes before dissipating. The ring for Burn #3 was approximately 15-20 meters above the pan, based on visual observation. The Burn #6 ring was approximately 30-50 meters above the pan. The particulates within the ring rotates in a circular motion from the inside of the ring to the outside. Figure 8 provides a general description of the smoke ring with the particulate motion.



Note: Not to Scale

Figure 8. General Description of Smoke Rings Generated From Burns #3 and #6.

Removal Efficiency for Nitroglycerin

Using the mass balance data previously calculated, estimations of the removal efficiency for nitroglycerin revealed open burning removed more than 99.9999 percent of the nitroglycerin in the propellant. The estimation uses the 3.1 lb ash/1000 lb waste from the mass balance. It also uses the detection limit for nitroglycerin (0.005 weight percent) for samples where the nitroglycerin in the ash is below the detection limit. Table VII summarizes the calculations.

Table VII. Nitroglycerin Removal Efficiency for Open Burning of AA-2 Waste

Burn #	Waste Weight (lb)	NG Weight Fraction	NG Weight (lb)	Ash Weight (lb)	NG Weight Fraction	Ash NG Weight (lb)	Removal Efficiency (%)
1	420.5	0.37	155.6	1.30	0.000064	8.34E-05	99.9999464
2	427.0	0.38	162.3	1.32	0.000050	6.62E-05	99.9999592
3	371.5	0.37	137.5	1.15	0.000050	5.76E-05	99.9999581
4	421.0	0.38	160.0	1.31	0.000050	6.53E-05	99.9999592
5	424.0	0.37	156.9	1.31	0.000050	6.57E-05	99.9999581
6	431.5	0.36	155.3	1.34	0.000050	6.69E-05	99.9999569
7	426.0	0.37	157.6	1.32	0.000100	0.000132	99.9999162

Worst Case Analysis Using INPUFF

Using the worst case meteorological conditions, the adiabatic flame temperature, and a burn duration of fifteen (15) seconds, a worst case analysis for the open burning grounds using NOSIH AA-2 propellant is performed. The analysis uses the INPUFF™ model from Trinity Software and assumes that all of the lead and copper releases to the air. Additionally, a NO_x analysis assuming all of the fuel nitrogen forms NO_x compounds is generated. Refer to Appendix B for the model description and analysis.

Table VIII summarizes the highest five-minute concentrations generated from the model along with the permitted Short-Term Exposure Limits (STELs) for each compound. Note that the STELs are based on fifteen-minute exposures.

Table VIII. INPUFF Model Exposures and Short-Term Exposure Limits for Worst Case Model

Compound	5-Minute Exposure (ug/m^3)	15-Minute Exposure (ug/m^3)	15-Minute STEL (ug/m^3)
Lead	694	401	450
Copper	191	110	NA
NOx	5.34 ppm	3.08	5 ppm

Note : Copper does not have a 15-minute STEL.
The 8-hour Time-Weighted Average for copper is 200 ug/m^3.

Discussion

Meteorological Conditions

The meteorological conditions during the study cover the spectrum of events that would be expected for open burning. The stability classes of the burns, A-D, represent all of the conditions possible at the time of the burns. The burns occur at 2:30 PM to avoid morning inversions, which would be classes E-F. Inversions lead to low mixing heights, which would hinder plume dissipation. The plume heights from the open burn tests are much lower than even the lowest observed mixing height of 280 meters.

The location of the weather station is approximately ten miles from the burn site. Fortunately, no fronts entered the area between 2:30 PM and 7:00 PM on the burn dates to alter the weather profile at ground level.

Burn Duration

The burn duration is a function of several meteorological parameters, including the ambient temperature, the air moisture content, the mixing height, and the ground level lapse rate. Using these characteristics, a burn duration parameter is established which has a strong linear correlation to the burn duration.

The ambient temperature has a strong inverse relationship to the burn duration. This is most likely due to the increased time necessary for the starter propellant bag to ignite the bulk propellant. The waste propellant is placed on the pan several hours before the burn, so the waste temperature reaches ambient conditions before the burn. With cooler ambient temperatures, the waste will require an increased amount of thermal energy to ignite.

The ground level lapse rate has a strong linear relationship to the burn duration. The flames from the burns are as high as thirty meters. The temperature differences, though small, may have an effect on the kinetics of the burn.

The mixing height and the moisture content are weaker relationships to the burn duration. Generally, the burn duration increases with a decrease in mixing height. The mixing height is an indication of the vertical mixing quality. A low mixing height would indicate that the gases are contained longer, leading to an increased burn duration.

Finally, burn duration is a weak function of the moisture content. The general trend is that a increase in the moisture content leads to decreased burn durations. The water vapor acts as a heat sink, which would reduce the thermal energy for the burn.

Plume Velocity Profiles

A large variation in the plume velocity profiles is observed during the open burn study. The profiles are illustrated in Figure 2 of Appendix D-H. The velocity profile for the burns depends on the location of the ignition bag as well as weather conditions.

In many cases, the velocity increases with increased height to a maximum value. This is because the velocity profile is a combination of the plume from the starter propellant bag and the bulk waste propellant plume. A plume is generated from the starter propellant bag upon ignition. Once the bulk propellant ignites, a large plume forms which has more of an initial velocity. The combination of the two plumes produces a profile which has an increased velocity with increased height.

The only occasion where the trend did not hold was for Burn #3. Refer to Figure E-2 for the velocity profile. During the time of the burn, a fine mist was falling over the area. The mist has a momentum that opposes the plume momentum, generating a profile different from the general trends of the other profiles.

There is no observed correlation between the maximum plume velocities of the burns. The wind affected the profile of Burn #4, which produced an increased maximum plume velocity. Refer to Figure F-2 for the velocity profile.

Mass Balance for Metals

The data for the mass balance for metals is affected by the difficulty to remove the analytes from the clay pans. The ash is removed until none is visible over the pan area, but the lead and copper oxides adhere to the clay. A wire brush is used to loosen the clay for removal, but a significant amount of the analyte remains in the background samples. If a clean clay pan is used for each burn, one would expect more consistent results.

Additionally, the samples are corrected for moisture, and the large variations in the moisture content affect the concentrations. The samples were run with the moisture in them, and then the samples were corrected for moisture. This protocol is standard for RFAAP's analysis. A more scientific approach would be to dry the samples beforehand to remove the moisture initially.

The mass balance is conducted on the first burn, since the first burn uses fresh clay as the background sample. The mass balance results in over 99 weight percent of the lead and copper being released to the air. The protocol for modeling open burning events recommends assuming all of the metals are emitted to the air [11]. Based on the mass balance analysis, the assumption would hold in this case.

Clay Moisture Analysis

The clay moisture content decreased exponentially over the burn study. When the pans are cleaned and filled with new clay, water is added to mold and compact the clay so that the pan is uniform without any cracks. As the burns are generated, the moisture in the clay is removed.

The samples are collected in polyethylene samples bags and stored in a sample collection room in the analytical laboratory. The collection bags are standard samples bags used by the RFAAP analytical department. In fact, the bags are also used to collect the waste propellant. The waste samples have moisture contents of less than 0.5 weight percent after being stored for the same amount of time as the clay samples.

Removal Efficiencies for Nitroglycerin

The removal efficiencies for nitroglycerin in the propellant is over 99.9999 percent, using the mass balance data previously discussed. The required Destruction and Removal Efficiency (DRE) for nitroglycerin is 99.99 percent for RFAAP's incinerator permit. The data from the open burn study does not take into account the destruction of nitroglycerin. In order to determine a true DRE for open burning, samples of the plume would have to be analyzed for nitroglycerin.

Smoke Ring Effects

The smoke rings generated during Burns #3 and #6 are created by the combination of plumes created by the starter propellant and the bulk waste. The starter propellant generates an initial plume above the pan. Because there is no wind during the burns, the initial plume stays over the pan when the bulk propellant ignites. The flame and bulk plume penetrate the initial plume, generating the smoke ring.

Figure 8 illustrates the general shape of the smoke ring. The center of the ring is warmer than the outside. The combination of buoyancy effects due to the temperature difference and the angular momentum of the particulates maintains the ring shape. Once the temperature inside the ring cools, the ring breaks down and dissipates.

Worst Case Analysis using INPUFF™ Model

A worst-case analysis is performed using the INPUFF™ model to estimate ground level concentrations along the New River. Appendix B describes all of the parameters associated with the model. Table VIII summarizes the highest concentrations and the short-term limits. Note that Army regulations restrict the number of pans burned to eight per day. This analysis covers the potential emissions of all sixteen pans being burned.

The INPUFF analysis for the open burning of NOSIH AA-2 exposes problems with using the model on short-duration episodes. The major difficulties of the analysis are the plume height calculations and the restrictions associated with the sampling times for short-term episodes.

1. Plume Height Calculations

The calculations for the plume height used by INPUFF™ overestimates plume heights substantially, and this has a direct impact on the ground level concentrations associated with the open-burn.

The equations and protocol for plume heights were developed by Briggs [1]. There are two empirical equations for plume height. The first involves momentum rise, where the velocity of the stack gas and the wind speed control the plume rise. The other situation is buoyancy plume rise, which depend on the temperature difference between the stack gas and the ambient temperature. INPUFF™ uses a variation of the buoyancy plume rise equation.

Table IX compares the plume heights generated using the buoyancy and the momentum plume rise equations.

Table IX. Comparison Between Buoyancy Plume Height and Momentum Plume Height

Burn #	Buoyancy Height (m)	Momentum Height (m)
1	634.9	49.0
2	308.1	24.2
3	1908.6	144.9
4	354.0	27.7
5	597.4	46.0
6	1907.9	144.9
7	187.8	15.1

The buoyancy plume height uses a stack temperature of 1547°C (1820°K), and the Burns #3 and #6 uses a wind speed of 0.5 m/s.

The plume heights from the burn study, based on visual observation, were more in accordance with the momentum plume rise than the buoyancy plume rise. The original FORTRAN code for the INPUFF model had the option of inputting the plume heights. The Trinity Software version did not have such an option.

There are two main factors that can account for the differences. The adiabatic flame temperature approximates the temperature at the tip of the flame and may overestimate the plume temperature. Also, the temperature profile with elevation is not included in the model, which alters the temperature profile of the plume. The combination of these factors would lead to overestimated plume heights.

The overestimation of the plume heights would lead to alterations in the concentration profile. The maximum ground level concentrations would be closer to the source with lower plume heights. Additionally, the ground level concentrations would be higher over an area closer to the source.

2.Sampling Time Restrictions

A problem with the INPUFF model is the sampling time for short-term events. The model allows the user to input up to twenty source emission updates for each episode. The sampling time cannot exceed the total time of the source emission updates. For continuous sources or sources with long emission times, the sampling time is not a problem. For example, a total two-hour emission time can have up to eight fifteen-minute sampling times for each receptor.

The regulations for Short-Term Exposure Limits (STELs) are based on fifteen-minute exposure times. Utilizing the full twenty source updates, each update would have to be at least forty-five seconds in length. The burns for this study are thirteen to twenty seconds in length. Using fifteen seconds as a burn time and the full complement of source updates, the sampling time would be five minutes in length. Correlations for adjusting concentrations for different exposure periods are used to estimate the 15-minute exposure concentration [2], but they are for continuous sources and would be expected to overestimate the 15-minute concentrations for open burning.

Summary and Conclusions

The characteristics of the open burning of NOSIH AA-2 sheet waste propellant at Radford Army Ammunition Plant were studied in this study. The project considered the plume and burn characteristics, the removal of nitroglycerin from the waste, the emission of metals into the air, and the modeling of pollutant emissions from open burning. Based on the results of the study, the following conclusions were derived:

- The plumes generated from the open burning of NOSIH AA-2 in the sheet form are well below the mixing heights. By burning at 2:30 PM and under Army guidelines, the risk of inversions is essentially eliminated.

- The burn duration of NOSIH AA-2 in the sheet form is a function of the meteorological conditions, assuming equal weights of propellant are burned.

- The moisture content in the clay pan decreased exponentially after subsequent burns of NOSIH AA-2 in the sheet form.

- The assumption that all of the metals in the propellant are emitted to the air holds for NOSIH AA-2 in the sheet form.

- The removal efficiency of nitroglycerin in NOSIH AA-2 in the sheet form is over 99.9999 percent. Plume samples will have to be evaluated to determine the Destruction and Removal Efficiency.

- The modeling of the open burns of NOSIH AA-2 exposed limitations of the INPUFF model in the plume height calculations and the sampling time method. These limitations hinder the estimation of ground level receptor concentrations.

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Appendix A.
Adiabatic Flame Temperature Model

Introduction

In order to model the plume height of an open burn using INPUFF™, an estimate of the initial plume temperature has to be established. Very few instruments, such as thermocouples, can withstand the temperatures generated by the burns. Additionally, the reading would have to be done remotely due to safety considerations. Consequently, a model to determine the adiabatic flame temperature was developed to estimate the initial plume temperature.

Model Description

The model calculates the adiabatic flame temperature based on meteorological and burn characteristics. Input variables include: mass of propellant, ambient temperature, propellant moisture, air moisture, percent conversion (mass burned/mass propellant), percent excess air, and ash residue specific heat. From these variables, adiabatic flame temperatures were estimated.

The model was designed on a Microsoft EXCEL™ spreadsheet in the following manner: a well-insulated balloon containing the stoichiometric amount of air (or more, depending on the amount of excess air) and propellant is ignited. All of the thermal energy generated due to combustion is used to heat the combustion gases, excess air, and any residue left. The balloon is free to expand ideally, and the temperature and gas volume are calculated.

Model Assumptions

The following assumptions were made in developing the model:

1. Complete Combustion - No products of incomplete combustion were generated.
2. All water exists in the vapor phase.
3. The nitrogen in the air was inert. All of the nitrogen oxide compounds were generated by the propellant fuel nitrogen.
4. Conversion was uniform for all compounds. Each compound had the same conversion ratio as the overall conversion.
5. The composition of the waste propellant is assumed to be that of the final product. This is a reasonable assumption considering that most of the propellant was rejected due to sheet thickness.

Model Equations

The calculation of the adiabatic flame temperature was based on an overall energy balance:

$$Q = \Delta H = (m_{fuel})(\Delta H^{\circ}_{comb}) - (m_{fuel})\int Cp_{fuel}dT - (m_{gases})\int Cp_{gases}dT - (m_{ash})\int Cp_{ash}dT = 0 \qquad \text{(A-1)}$$

Q = Heat generated/lost (BTU)
ΔH = Enthalpy generated/lost (BTU)
m_{fuel} = Amount of fuel (g)
ΔH°_{comb} = Standard heat of combustion at 25°C and 1 atm (BTU/g)
Cp_{fuel} = Heat capacity of fuel (BTU/g/°C)
m_{gases} = Amount of gases (g)
Cp_{gases} = Heat capacity of gases (BTU/g/°C)
m_{ash} = Amount of ash (g)
Cp_{ash} = Heat capacity of ash (BTU/g/°C)

The heats of combustion were calculated using the standard heats of formation [4]:

$$\Delta H^{\circ}_{comb} = \Sigma(z_{i,prod})(\Delta Hf_{i,prod}) - \Sigma(z_{j,react})(\Delta Hf_{j,react}) \quad \text{(A-2)}$$

ΔH°_{comb} = Standard heat of combustion (BTU/mole)
$z_{i,prod}$ = Stoichiometric coefficient of ith product
$\Delta Hf_{i,prod}$ = Standard heat of formation for ith product (BTU/mole)
$z_{j,react}$ = Stoichiometric coefficient of jth reactant
$\Delta Hf_{j,react}$ = Standard heat of formation for jth reactant (BTU/mole)

Heat capacities for the fuel were estimated using Kopp's Rule [4]. Table A-I shows the heat capacity estimates for the individual atoms in a compound. The sum of all of the individual capacities provides an overall estimate for the compound heat capacities.

Table A-I. Atomic Heat Capacities for Kopp's Rule

Element	Solids	Liquids
C	7.5	12
H	9.6	18
B	11	20
Si	16	24
O	17	25
F	21	29
P	23	31
S	26	31
All Others	26	33

Note: All heat Capacities in J/g-atom/°C.

(From Felder, Rousseau, Elementary Principles of Chemical Processes, Second Edition, John Wiley and Sons, New York, 1986, p. 352.)

Heat capacities for the gases as a function of temperature were based on correlations from Felder and Rousseau [4]. Once the temperature is established, estimates for the volume of gas were calculated using the ideal gas law.

Table A-II is the output from an example combustion experiment.

Table A-II Example Calculation Using Adiabatic Flame Temperature Model

Dry Mass of AA-2 (g)	191134
Moisture (wt %)	0.6
Conversion (%)	100
Ambient Temp (°C)	18.9
Excess Air (%)	0
Air Moisture (g H2O/g DA)	0.012
Residue Specific Heat (BTU/lb°F)	0.25

	Dry Wt. Fract.	Wet Wt. Fract.	Mass (g)	Hc (BTU/g)	Comb. (BTU)
Nitrocellulose	.51	.507	96896.96	-9	-872072.62
Nitroglycerine	.386	.384	73337.70	-6.26	-459093.99
2-Nitrodiphenyl Amine	.02	.02	3799.88	-25.5	-96896.96
Di-n-Propyl Adipate	.016	.016	3039.90	-30.4	-92413.10
LC-1215					
Lead Resorsylate	.027	.027	5129.84	-9.4	-48220.49
Copper Salicylate	.013	.013	2469.92	-15.9	-39271.77
Triacetin	.027	.027	5129.84	-22.7	-116447.34
Other	.001	.001	189.99		
Total Dry Fraction	1.	.994			
Water	.006	.006	1146.80		
Totals	1.006	1.	191140.84		-1724416.268

Combustion Gas Analysis

	MW (g/g-mol)	Mol Reacted	CO2 (mol)	NO (mol)	H2O (mol)	PbO (mol)	CuO (mol)
Nitrocellulose	296	327.3545887	1964.127532	982.06377	982.0637661	0	0
Nitroglycerine	227	323.0735586	1938.441352	969.22068	1615.367793	0	0
2-Nitrodiphenyl Amine	214.2	17.73987262	212.8784715	35.479745	88.69936311	0	0
Di-n-Propyl Adipate	230.3	13.19975933	158.3971119	0	145.1973526	0	0
LC-1215							
Lead Resorsylate	360	14.24955268	99.74686879	0	35.62388171	14.24955	0
Copper Salicylate	200	12.34961233	86.44728628	0	30.87403082		12.34961
Triacetin	218.2	23.50980278	211.588225	0	164.5686194	0	0
Totals		731.4767471	4671.626847	1986.7642	3062.394807	14.24955	12.34961

Temperature Analysis

Warming Fuel

	Cp (BTU/g °C)	Mass (g)	m*Cp (BTU/°C)
Nitrocellulose	1.18E-03	96896.96	114.1446168
Nitroglycerine	1.26E-03	73337.70	92.40549924
2-Nitrodiphenyl Amine	1.21E-03	3799.88	4.578856262
Di-n-Propyl Adipate	1.52E-03	3039.90	4.623694855
LC-1215			
Lead Resorsylate	5.13E-04	5129.84	2.62904247
Copper Salicylate	8.42E-04	2469.92	2.079674716
Triacetin	1.32E-03	5129.84	6.776517274
Water	4.12E-03	1146.80	4.72483248
Totals	0.0119595	190950.85	231.9627341

Heat Balance

Warming Fuel	1414.972678	BTU
Warming Air	1746.300569	BTU
Combustion	-1721865.91	BTU
Residue	0	BTU
Gas Temp	1545.767761	°C
Overall Q	.	BTU

Combustion Gases	A	B	C	D	Energy (BT
CO2	36.11	2.12E-02	-9.62E-06	1.87E-09	367966.3
NO	29.5	4.09E-03	-9.75E-07	9.13E-11	100527.7
H20(v)	33.46	3.44E-03	2.53E-06	-8.98E-10	849002.6
N2	29	1.10E-03	1.91E-06	-7.18E-10	399492.7
O2	29.1	1.16E-02	-2.03E-06	3.28E-10	2.816552
PbO	43	0	0	0	917.4711
CuO	43	0	0	0	795.1417

Appendix B.
Worst-Case Analysis for Open Burning of NOSIH AA-2

Introduction

An analysis of a worst-case open-burn situation at the Radford Army Ammunition Plant was performed using NOSIH AA-2 propellent in the sheet form. The analysis uses the Trinity INPUFF™ model and the meteorological and burn characteristics of the open burn tests. The tests were for lead, copper, and total No_x emissions.

Model Description

The INPUFF model uses the Gaussian plume equation for pollutant dispersion [9]:

$$C(x,y,z,H) = Q/[(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z] \exp[-.5[(x-ut)/\sigma_x]^2] \exp[-.5[y/\sigma_y]^2]$$
$$\{\exp[-.5[(z+H)/\sigma_z]^2]+ \exp[-.5[(z-H)/\sigma_z]^2\} \qquad \text{(B-1)}$$

C = Concentration, ug/m^3
Q = Emission rate, g/s
σ_x = Dispersion coefficient in the x- direction, m
σ_y = Dispersion coefficient in the y-direction, m
σ_z = Dispersion coefficient in the z-direction, m
x = Receptor location in the x - direction, m
y = Receptor location in the y - direction, m
z = Receptor location in the z - direction, m
u = Wind speed at stack height, m/s
H = Mixing height, m
t = Time, s

The advantages of using INPUFF rather than conventional modeling is that the dispersion coefficients are functions of time. In conventional Gaussian modeling, the coefficients are functions of distance in the x-direction. With this difference, INPUFF can model events where the meteorological conditions change over time. Additionally, the INPUFF model assumes that the plume that the x and y dispersion coefficients are equal (ie the plume is circular).

Worst-Case Analysis Model Assumptions

The following assumptions are used in the INPUFF model:

- All sixteen pans are burned using 1000 pounds of propellant per pan.
- All of the metals are emitted in the air.
- All of the fuel nitrogen is converted to NO2 to maximize the mass of emissions.
- The duration for the burn is fifteen seconds per burn.
- The stability class is D stability. This would be the worst case for the burns based on the time of day.
- The wind speed is 6.7 m/s. This is the maximum allowed for burns based on Army regulations.
- The wind direction is 105°. This would carry the plumes over the New River.
- The pans are ignited in order of distance from the Grounds Office. The pan farthest from the office is ignited first.
- The initial plume tempereature is 1820°K.
- The mixing height used is 274 meters. This is the lowest mixing height observed during the study.

Additonal Model Parameters

Three 3x3 receptor grids are used over the model area. Figure B-1 illustrates the receptor grids and the plume generated from the pan farthest from the Grounds Office. Figure B-2 illustrates the plume and receptors for the pan closest to the Grounds Office.

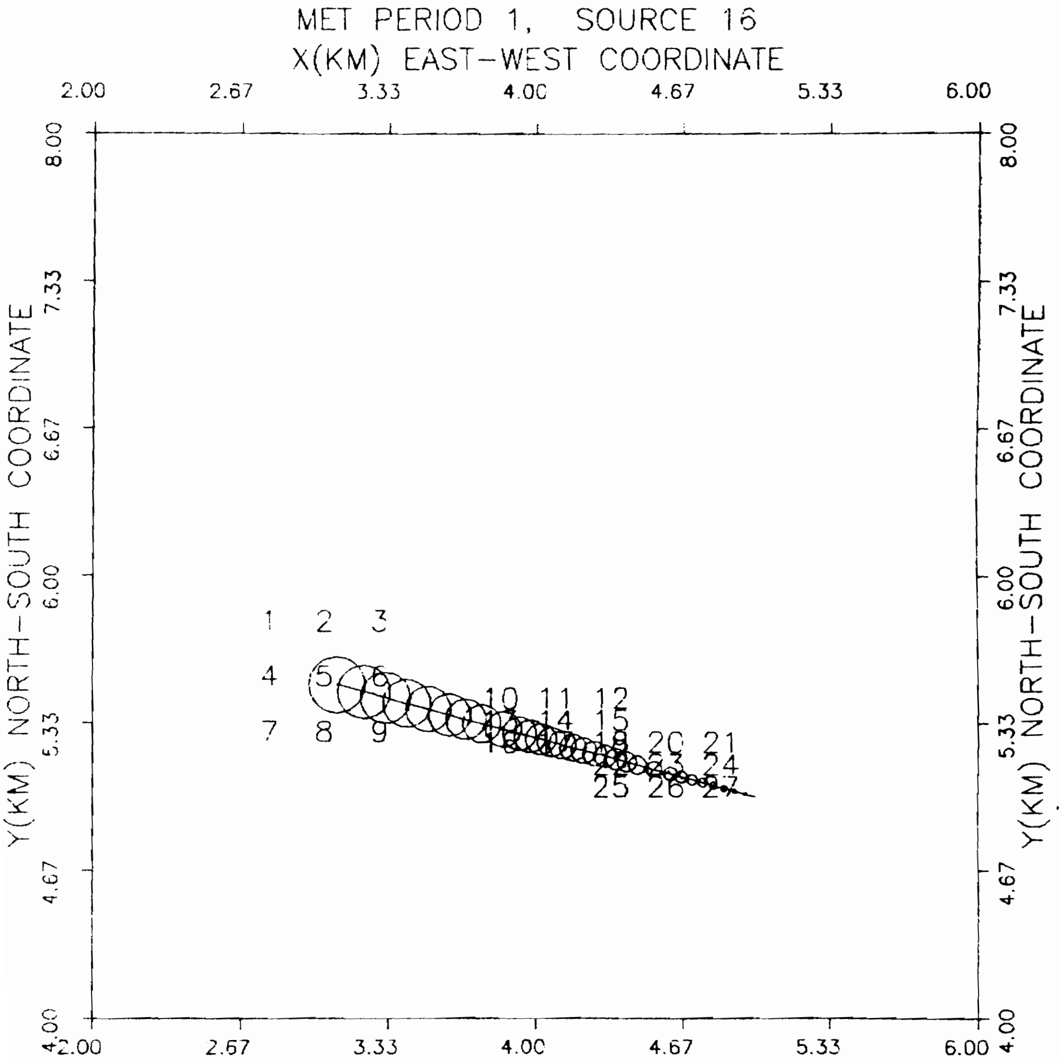

Figure B-1. Plume and Receptor Grids for Pan Farthest from Open Burning Ground Office.

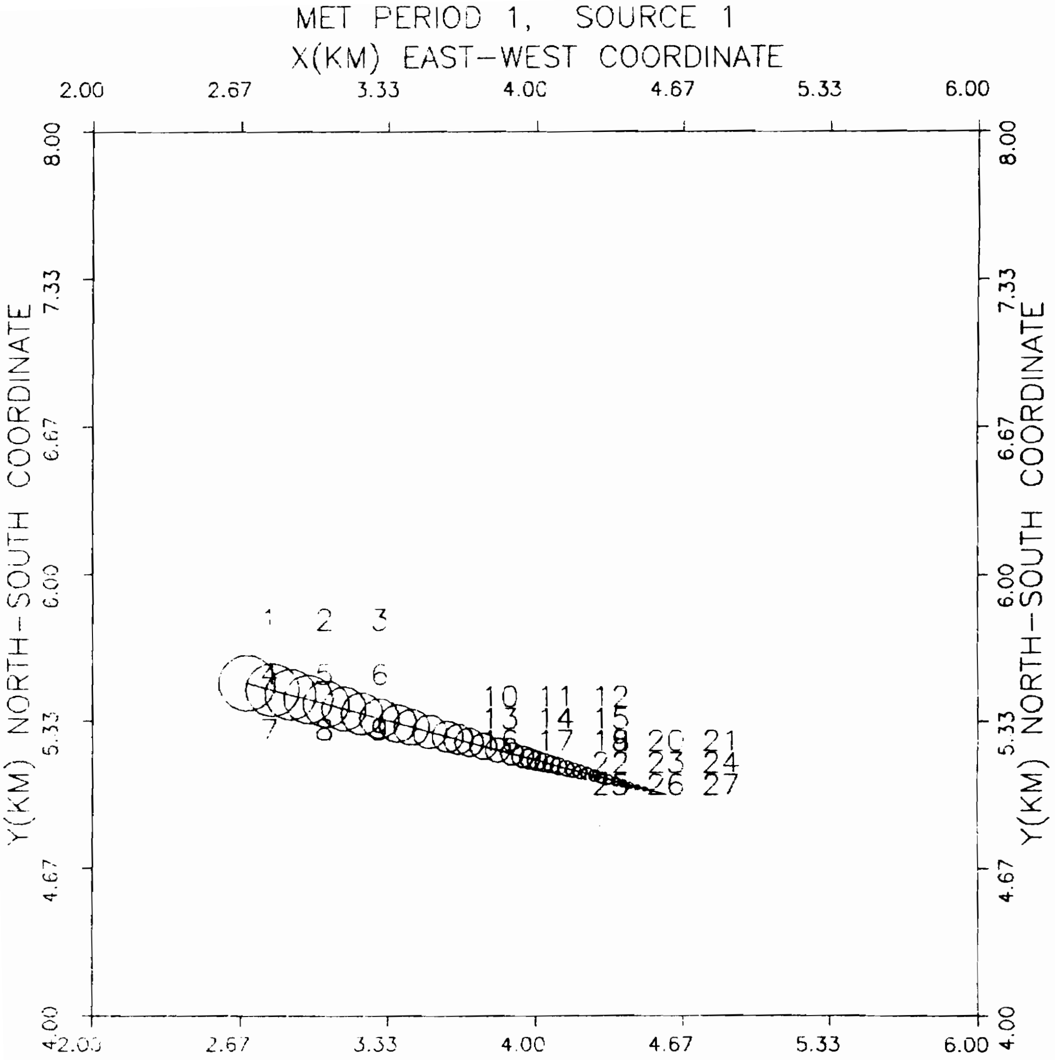

Figure B-2. Plume and Receptor Grids for Pan Nearest to the Open Burning Ground Office.

Model Results

Using the assumptions and input variables, the ground-level concentrations of lead, copper, and total No_x are estimated. The plume height is estimated to be 183 m, which is under the mixing height. Table B-I summarizes the five-minute concentrations of the analytes at each receptor.

Table B-I. Summary of Five-Minute Concentrations for the Worst-Case Analysis

Receptor Number	Lead Concentration (ug/m^3)	Copper Concentration (ug/m^3)	NOx Concentration (ppm)
1	0.00	0.01	0.00
2	0.00	0.00	0.00
3	0.00	0.00	0.00
4	0.00	0.09	0.00
5	0.00	0.09	0.00
6	0.00	0.30	0.01
7	0.06	0.02	0.00
8	0.08	0.02	0.00
9	2.43	0.67	0.02
10	95.16	26.14	0.73
11	3.44	0.95	0.03
12	0.00	0.00	0.00
13	390.40	107.20	3.01
14	160.80	44.18	1.24
15	0.87	0.24	0.01
16	270.70	74.36	2.08
17	647.40	177.80	4.98
18	310.90	85.39	2.39
19	311.00	85.39	2.39
20	0.00	0.00	0.00
21	0.00	0.00	0.00
22	693.90	190.60	5.34
23	569.70	156.50	4.39
24	0.00	0.00	0.00
25	1.76	0.48	0.01
26	5.15	1.42	0.04
27	0.00	0.00	0.00

Appendix C.
Data from Burn #1 - 9/12/1996

Table C-I. Propellant Weight Data for Burn #1 - 9/12/96

Container #	Propellant Weight (lbs)	Measurement Error (lbs)
1	67.5	0.5
2	67.0	0.5
3	67.5	0.5
4	67.0	0.5
5	67.0	0.5
6	67.0	0.5
7	66.5	0.5

Gross Weight	469.5	lbs
- Container Weight	-49.0	lbs
Net Weight	420.5	lbs
Error in Net Weight	14.25	lbs
Relative Error	3.39	%

Note: Net weight is based on container weight of 7.0 ± 0.5 lbs.

Table C-II. Meteorological Data for 9/12/96

Ambient Temperature = 26.1°C
Dry Bulb Temperature = 26.1°C
Wet Bulb Temperature = 21.6°C
Wind Speed = 0.9-2.0 m/s
Wind Direction = 75°

Maximum Surface Temperature: 26.1 °C
78.98 °F

Temp (°C)	Relative Altitude (m)	Absolute Altitude (m)	Temp (°F)	Balloon Altitude (ft)	Adiabatic Altitude (ft)
22.50	0.00	640.00	72.50	0.00	1200.00
22.70	104.00	744.00	72.86	341.12	1133.33
15.90	832.00	1472.00	60.62	2728.96	3400.00
9.90	1577.00	2217.00	49.82	5172.56	5400.00
7.80	2036.00	2676.00	46.04	6678.08	6100.00
4.50	2447.00	3087.00	40.10	8026.16	7200.00
2.60	2693.00	3333.00	36.68	8833.04	7833.33
2.20	2763.00	3403.00	35.96	9062.64	7966.67
1.80	2835.00	3475.00	35.24	9298.80	8100.00

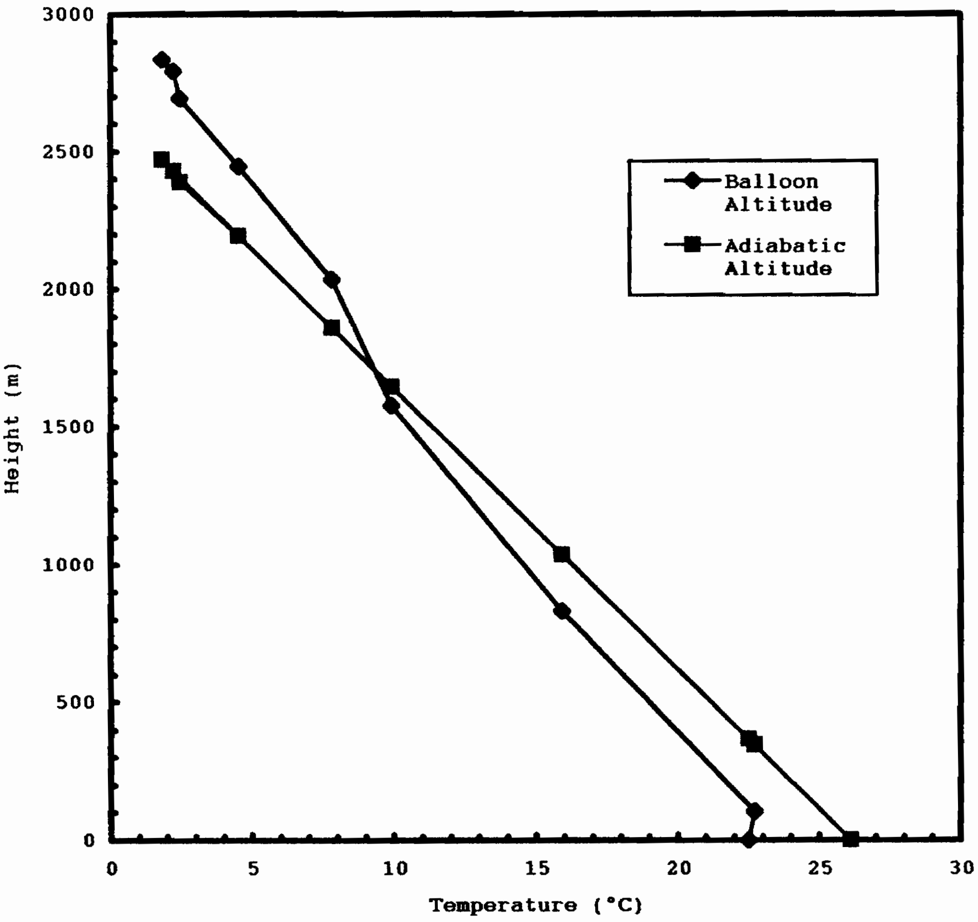

Figure C-1. Mixing Height Diagram for Burn #1 - 9/12/96

Note: Meteorological data from 7 PM balloon release at the National Weather Service station in Blacksburg.

Table C-III. Burn Duration Data for Burn #1 - 9/12/96

Test #	Burn Duration (sec)
1	13.65
2	13.56
3	13.65
4	13.82
5	13.81
6	13.78
7	13.81
8	13.75
9	13.53
10	13.78
Average =	13.71
Std. Deviation =	0.11

Appendix D.
Data from Burn #2 - 9/19/96

Table D-I. Propellant Weight Data from Burn #2 - 9/19/96

Container #	Propellant Weight (lbs)	Measurement Error (lbs)
1	54.0	0.5
2	56.0	0.5
3	65.5	0.5
4	65.5	0.5
5	63.0	0.5
6	17.5	0.5
7	55.5	0.5
8	57.5	0.5
9	55.5	0.5

Gross Weight	490.0	lbs
- Container Weight	-63.0	lbs
Net Weight	427.0	lbs
Error in Net Weight	16.26	lbs
Relative Error	3.81	%

Note: Net weight is based on container weight of 7.0 ± .5 lbs.

Table D-II. Meteorological Data for 9/19/96

Ambient Temperature = 22.2°C
Dry Bulb Temperature = 24.4°C
Wet Bulb Temperature = 21.7°C
Wind Speed = 3.1 m/s
Wind Direction = 100°

Maximum Surface Temperature: 22.2 °C
71.96 °F

Temp (°C)	Relative Altitude (m)	Absolute Altitude (m)	Temp (°F)	Balloon Altitude (ft)	Adiabatic Altitude (ft)
17.40	0.00	640.00	63.32	0.00	1600.00
16.20	155.00	795.00	61.16	508.40	2000.00
9.70	866.00	1506.00	49.46	2840.48	4166.67
8.60	987.00	1627.00	47.48	3237.36	4533.33
8.60	1016.00	1656.00	47.48	3332.48	4533.33
8.70	1046.00	1686.00	47.66	3430.88	4500.00
10.20	1106.00	1746.00	50.36	3627.68	4000.00
10.60	1136.00	1776.00	51.08	3726.08	3866.67
10.70	1196.00	1836.00	51.26	3922.88	3833.33
4.20	2466.00	3106.00	39.56	8088.48	6000.00
3.30	2745.00	3385.00	37.94	9003.60	6300.00
0.10	3271.00	3911.00	32.18	10728.88	7366.67
-0.90	3441.00	4081.00	30.38	11286.48	7700.00
-5.70	3972.00	4612.00	21.74	13028.16	9300.00
-5.60	4178.00	4818.00	21.92	13703.84	9266.67
-8.50	4679.00	5319.00	16.70	15347.12	10233.33
-12.20	5123.00	5763.00	10.04	16803.44	11466.67
-14.60	5467.00	6107.00	5.72	17931.76	12266.67

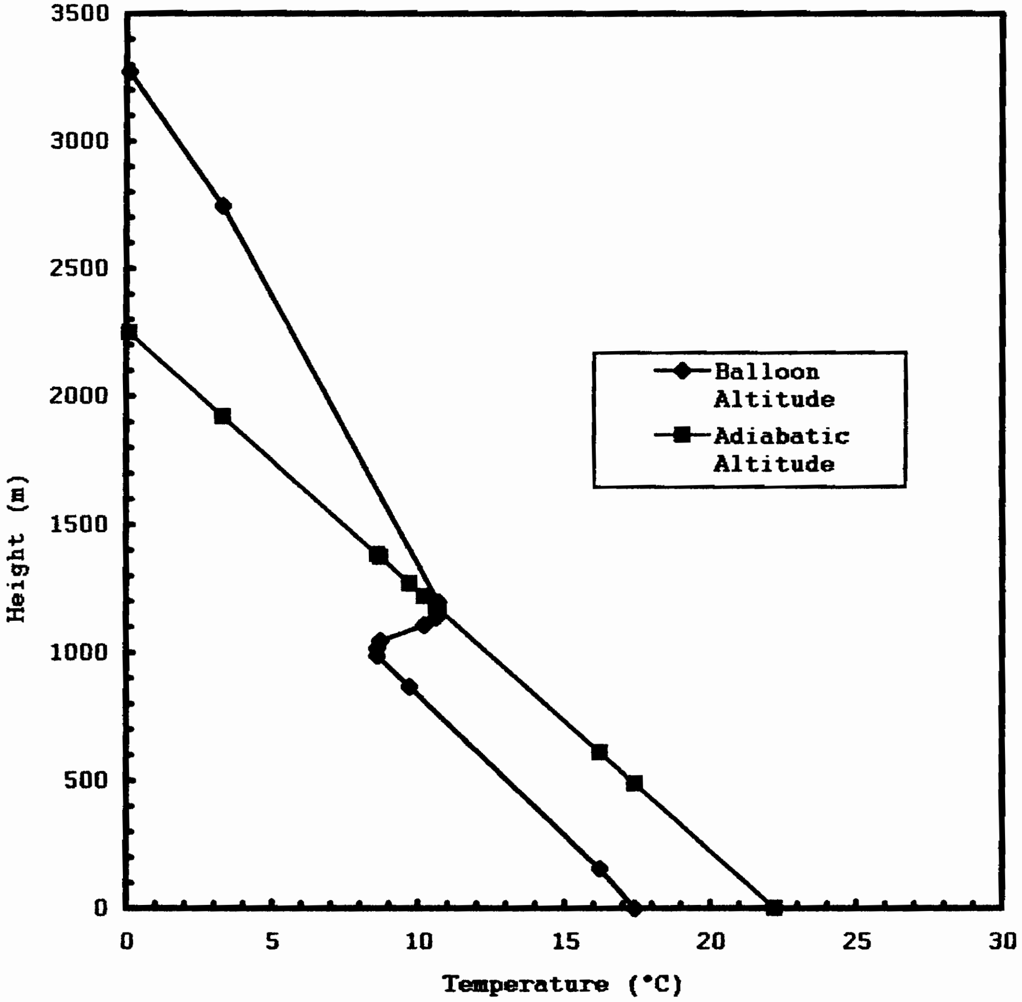

Figure D-1. Mixing Height Diagram for Burn #2 - 9/19/96

Note: Meteorological data from 7 PM balloon release at the National Weather Service station in Blacksburg.

Table D-III. Burn Duration Data for Burn #2 - 9/19/96

Test #	Burn Duration (sec)
1	16.12
2	16.21
3	16.06
4	16.25
5	16.31
6	16.31
7	16.16
8	16.07
9	16.10
10	16.19
Average =	16.18
Std Deviation =	0.09

Table D-IV. Velocity Profile Data for Burn #2 - 9/19/96

Reference Length: 3.51 ± .10m

Set #1 (8.13-11.64m Height)		Set #2 (11.64-15.15m Height)		Set #3 (15.15-18.66m Height)	
Test #	Time (s)	Test #	Time (s)	Test #	Time (s)
1	1.28	1	1.09	1	0.44
2	1.16	2	1.10	2	0.53
3	1.10	3	1.09	3	0.47
4	1.00	4	1.03	4	0.53
5	1.12	5	1.10	5	0.59
6	1.00	6	0.94	6	0.60
7	1.00	7	1.16	7	0.53
8	1.06	8	1.10	8	0.57
9	1.22	9	1.19	9	0.53
10	1.06	10	1.22	10	0.60
Average	1.10	Average	1.10	Average	0.54
Std. Dev.	0.10	Std. Dev.	0.08	Std. Dev.	0.05
Average Velocity =	3.19 m/s		3.19 m/s		6.51 m/s
Error =	0.13 m/s		0.12 m/s		0.21 m/s

Set #4 (18.66-22.17m Height)			Set #5 (22.17-25.68m Height)		
Test #	Time (s)		Test #	Time (s)	
1	0.47		1	0.56	
2	0.53		2	0.62	
3	0.56		3	0.59	
4	0.53		4	0.72	
5	0.57		5	0.72	
6	0.60		6	0.78	
7	0.50		7	0.78	
8	0.62		8	0.62	
9	0.56		9	0.62	
10	0.59		10	0.66	
Average	0.55		Average	0.67	
Std. Dev.	0.05		Std. Dev	0.08	
Average Velocity =	6.35	m/s		5.26	m/s
Error =	0.20	m/s		0.19	m/s

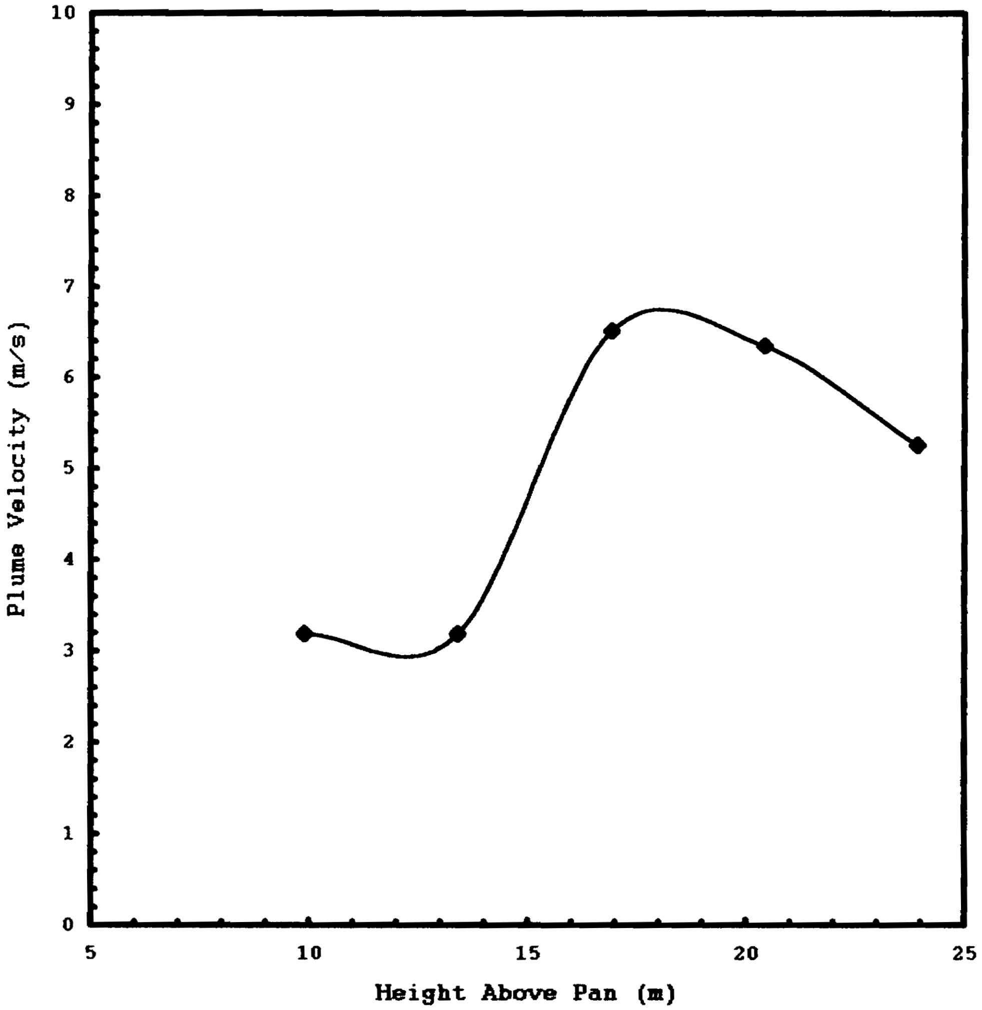

Figure D-2. Vertical Plume Velocity
Profile for Burn #2 - 9/19/96

Appendix E.
Data from Burn #3 - 9/26/96

Table E-I. Propellant Weight Data from Burn #3 - 9/26/96

Container #	Propellant Weight (lbs)	Measurement Error (lbs)
1	60.0	0.5
2	60.0	0.5
3	60.0	0.5
4	60.0	0.5
5	60.5	0.5
6	60.0	0.5
7	60.0	0.5

Gross Weight	420.5	lbs
- Container Weight	-49.0	lbs
Net Weight	371.5	lbs
Error in Net Weight	13.82	lbs
Relative Error	3.72	%

Note: Net weight is based on container weight of 7.0 ± 0.5 lbs.

Table E-II. Meteorological Data for 9/26/96

Ambient Temperature = 16.7°C
Dry Bulb Temperature = 18.9°C
Wet Bulb Temperature = 17.2°C
Wind Speed = 0 m/s (Note : Wind blocked due to valley effect)
Wind Direction = 0°

Maximum Surface Temperature: 16.7 °C
62.06 °F

Temp (°C)	Relative Altitude (m)	Absolute Altitude (m)	Temp (°F)	Balloon Altitude (ft)	Adiabatic Altitude (ft)
14.40	0.00	640.00	57.92	0	766.67
14.00	91.00	731.00	57.20	298.48	900.00
13.80	218.00	858.00	56.84	715.04	966.67
14.30	480.00	1120.00	57.74	1574.4	800.00
12.40	933.00	1573.00	54.32	3060.24	1433.33
7.70	1598.00	2238.00	45.86	5241.44	3000.00
7.50	1776.00	2416.00	45.50	5825.28	3066.67
6.70	1914.00	2554.00	44.06	6277.92	3333.33
5.60	2124.00	2764.00	42.08	6966.72	3700.00
4.20	2317.00	2957.00	39.56	7599.76	4166.67
4.70	2535.00	3175.00	40.46	8314.8	4000.00
4.80	2575.00	3215.00	40.64	8446	3966.67
4.20	2709.00	3349.00	39.56	8885.52	4166.67
1.20	3175.00	3815.00	34.16	10414	5166.67
0.00	3590.00	4230.00	32.00	11775.2	5566.67
-2.70	3923.00	4563.00	27.14	12867.44	6466.67
-6.60	4462.00	5102.00	20.12	14635.36	7766.67
-6.20	4538.00	5178.00	20.84	14884.64	7633.33
-7.30	4856.00	5496.00	18.86	15927.68	8000.00
-9.10	5082.00	5722.00	15.62	16668.96	8600.00
-9.70	5203.00	5843.00	14.54	17065.84	8800.00
-14.70	5871.00	6511.00	5.54	19256.88	10466.67
-14.60	5922.00	6562.00	5.72	19424.16	10433.33
-14.20	6001.00	6641.00	6.44	19683.28	10300.00
-14.20	6101.00	6741.00	6.44	20011.28	10300.00
-16.50	6401.00	7041.00	2.30	20995.28	11066.67
-18.70	6657.00	7297.00	-1.66	21834.96	11800.00
-20.80	6891.00	7531.00	-5.44	22602.48	12500.00

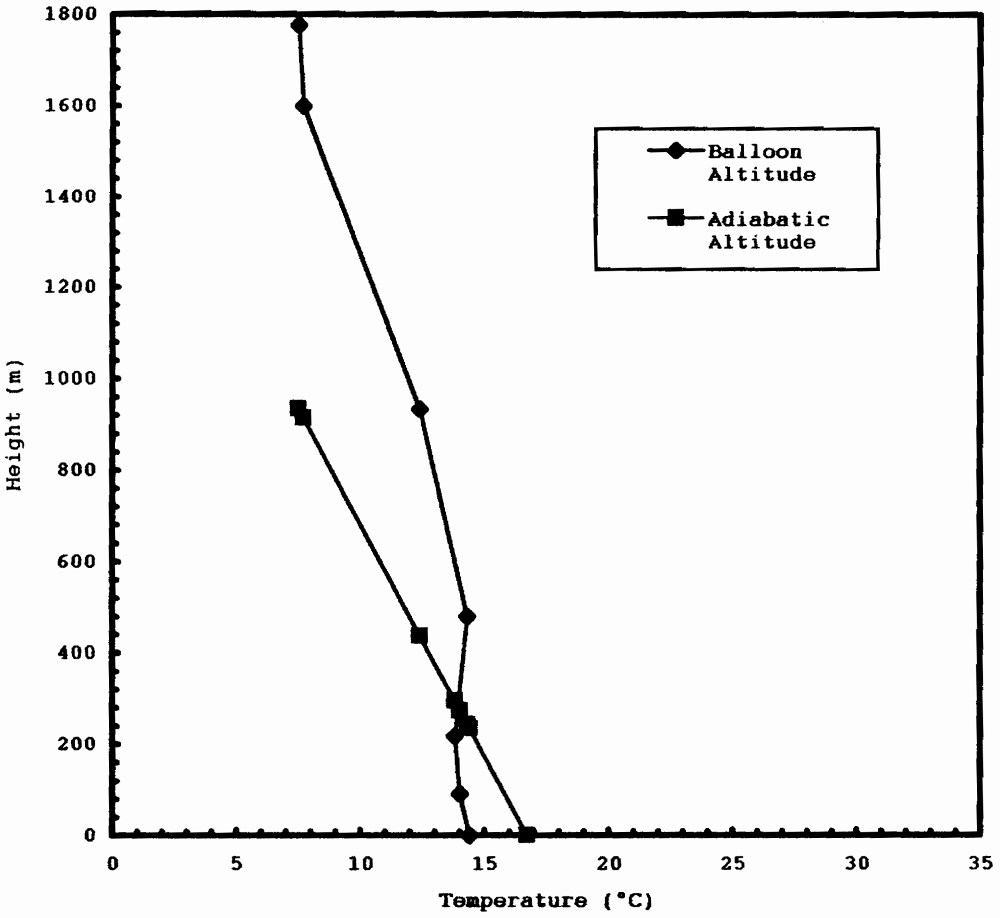

Figure E-1. Mixing Height Diagram for Burn #3 - 9/26/96

Note: Meteorological data from 7 PM balloon release at the National Weather Service station in Blacksburg.

Table E-III. Burn Duration Data for Burn #3 - 9/26/96

Test #	Burn Duration (sec)
1	17.53
2	19.41
3	20.63
4	19.91
5	19.31
6	19.10
7	19.06
8	20.38
9	19.00
10	18.87
Average =	19.32
Std. Deviation =	0.87

Table E-IV. Velocity Profile Data for Burn #3 - 9/26/96

Reference Length: 4.27 ± .10m

Set #1 (8.18-12.45m Height)		Set #2 (12.45-16.72m Height)		Set #3 (16.72-20.99m Height)	
Test #	Time (s)	Test #	Time (s)	Test #	Time (s)
1	0.63	1	0.62	1	0.66
2	0.65	2	0.56	2	0.72
3	0.5	3	0.65	3	0.65
4	0.62	4	0.72	4	0.72
5	0.68	5	0.69	5	0.66
6	0.6	6	0.66	6	0.65
7	0.66	7	0.56	7	0.66
8	0.59	8	0.69	8	0.63
9	0.65	9	0.62	9	0.69
10	0.63	10	0.69	10	0.68
Average	0.62	Average	0.65	Average	0.67
Std. Dev.	0.05	Std. Dev.	0.06	Std. Dev.	0.03
Average Velocity =	6.88 m/s		6.61 m/s		6.35 m/s
Error =	0.18 m/s		0.18 m/s		0.16 m/s

Set #4 (20.99-25.25m Height)			Set #5 (22.17-25.68m Height)		
Test #	Time (s)		Test #	Time (s)	
1	0.62		1	0.85	
2	0.82		2	0.84	
3	0.81		3	0.81	
4	0.78		4	0.72	
5	0.82		5	0.84	
6	0.90		6	0.78	
7	0.75		7	0.81	
8	0.72		8	0.91	
9	0.69		9	0.78	
10	0.78		10	0.82	
Average	0.77		Average	0.82	
Std. Dev.	0.08		Std. Dev.	0.05	
Average Velocity =	5.55	m/s		5.23	m/s
Error =	0.17	m/s		0.14	m/s

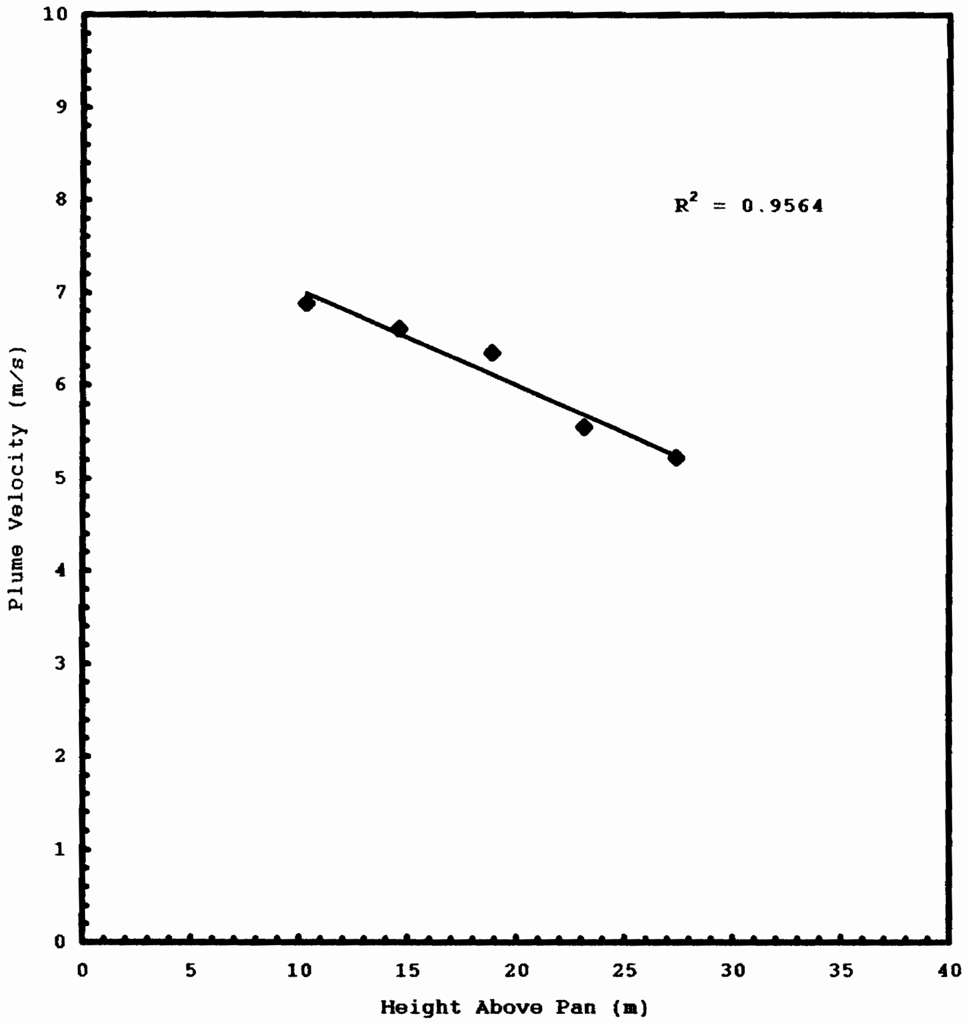

Figure E-2. Vertical Plume Velocity
Profile for Burn #3 - 9/26/96

Appendix F.
Data from Burn #4 - 10/03/96

Table F-I. Propellant Weight Data from Burn #4 - 10/03/96

Container #	Propellant Weight (lbs)	Measurement Error (lbs)
1	67.0	0.5
2	68.0	0.5
3	57.0	0.5
4	56.5	0.5
5	57.0	0.5
6	57.5	0.5
7	57.0	0.5
8	57.0	0.5

Gross Weight	477.0	lbs
- Container Weight	-56.0	lbs
Net Weight	421.0	lbs
Error in Net Weight	15.2	lbs
Relative Error	3.6	%

Note: Net weight is based on container weight of 7.0 ± 0.5 lbs.

Table F-II. Meteorological Data for 10/03/96

Ambient Temperature = 18.9°C
Dry Bulb Temperature = 19.4°C
Wet Bulb Temperature = 17.2°C
Wind Speed = 2.7 m/s
Wind Direction = 115°

Maximum Surface Temperature: 18.9 °C
66.02 °F

Temp (°C)	Relative Altitude (m)	Absolute Altitude (m)	Temp (°F)	Balloon Altitude (ft)	Adiabatic Altitude (ft)
10.40	8.00	648.00	50.72	26.24	2833.33
9.80	216.00	856.00	49.64	708.48	3033.33
8.80	342.00	982.00	47.84	1121.76	3366.67
10.80	661.00	1301.00	51.44	2168.08	2700.00
9.80	918.00	1558.00	49.64	3011.04	3033.33
6.40	1584.00	2224.00	43.52	5195.52	4166.67
4.00	2089.00	2729.00	39.20	6851.92	4966.67
5.20	2200.00	2840.00	41.36	7216.00	4566.67
4.00	2508.00	3148.00	39.20	8226.24	4966.67
-11.70	5160.00	5800.00	10.94	16924.80	10200.00
-14.10	5599.00	6239.00	6.62	18364.72	11000.00
-23.90	6830.00	7470.00	-11.02	22402.40	14266.67
-41.70	8860.00	9500.00	-43.06	29060.80	20200.00
-47.90	9614.00	10254.00	-54.22	31533.92	22266.67
-50.30	10070.00	10710.00	-58.54	33029.60	23066.67
-59.70	11490.00	12130.00	-75.46	37687.20	26200.00
-63.10	11941.00	12581.00	-81.58	39166.48	27333.33
-65.50	12457.00	13097.00	-85.90	40858.96	28133.33
-63.30	13260.00	13900.00	-81.94	43492.80	27400.00
-62.70	14191.00	14831.00	-80.86	46546.48	27200.00
-65.70	15058.00	15698.00	-86.26	49390.24	28200.00

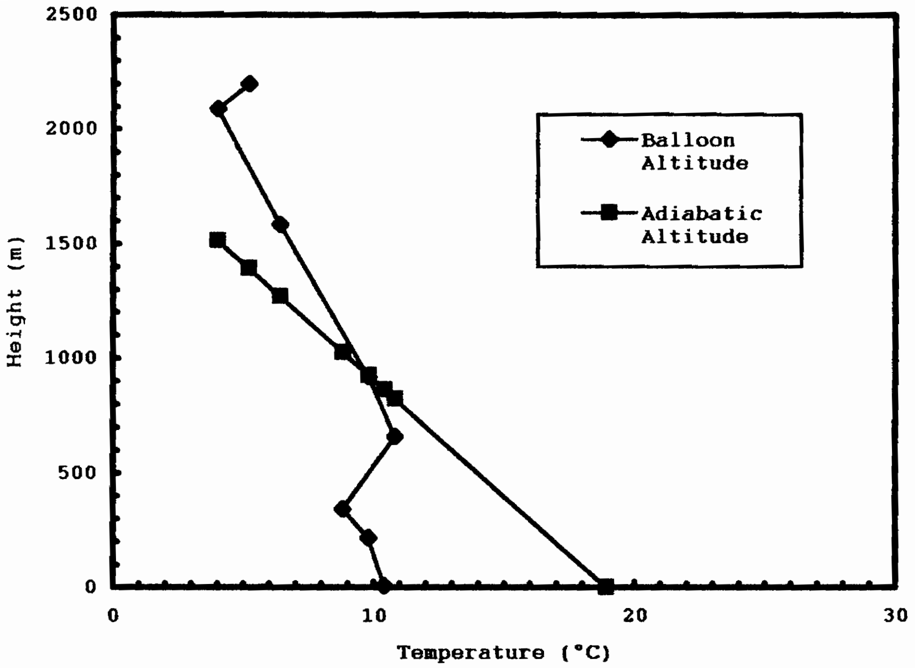

Figure F-1. Mixing Height Diagram for Burn #4 - 10/03/96

Note: Meteorological data from 7 PM balloon release at the National Weather Service station in Blacksburg.

Table F-III. Burn Duration Data for Burn #4 - 10/03/96

Test #	Burn Duration (sec)
1	19.06
2	19.03
3	18.56
4	18.78
5	19.47
6	19.19
7	19.31
8	19.40
9	19.34
10	19.35
Average =	19.15
Std Deviation =	0.29

Table F-IV. Velocity Profile Data for Burn #4 - 10/03/96

Reference Length: 4.27 ± .10m

Set #1 (8.18-12.45m Height)			Set #2 (12.45-16.72m Height)			Set #3 (16.72-20.99m Height)	
Test #	Time (s)		Test #	Time (s)		Test #	Time (s)
1	0.78		1	0.44		1	0.56
2	0.72		2	0.57		2	0.47
3	0.75		3	0.53		3	0.50
4	0.75		4	0.40		4	0.43
5	0.69		5	0.50		5	0.43
6	0.78		6	0.44		6	0.47
7	0.78		7	0.53		7	0.50
8	0.81		8	0.53		8	0.47
9	0.78		9	0.56		9	0.44
10	0.68		10	0.50		10	0.44
Average	0.75		Average	0.50		Average	0.47
Std. Dev.	0.04		Std. Dev.	0.06		Std. Dev.	0.04
Average Velocity =	5.68	m/s		8.54	m/s		9.07 m/s
Error =	0.14	m/s		0.23	m/s		0.23 m/s

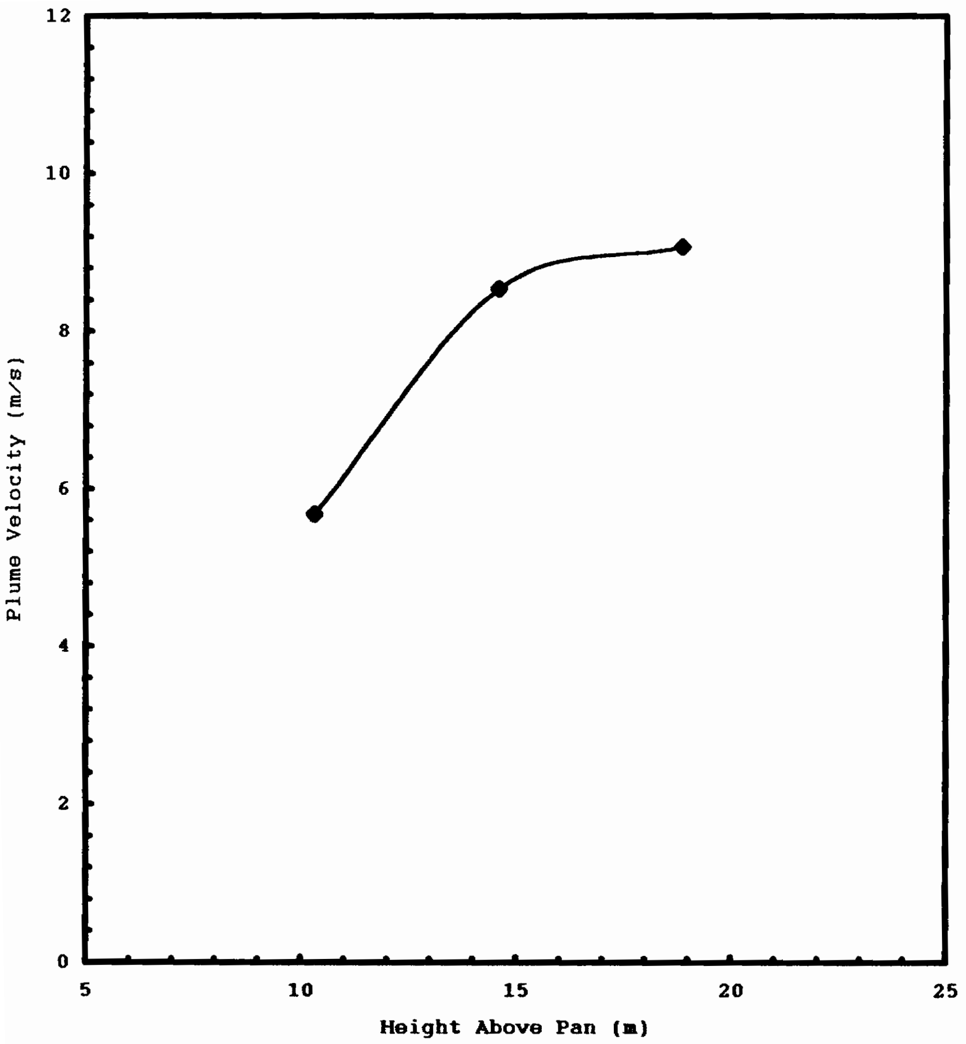

Figure F-2. Vertical Plume Velocity Profile for Burn #4 - 10/03/96

Appendix G.
Data from Burn #5 - 10/10/96

Table G-I. Propellant Weight Data from Burn #5 - 10/10/96

Container #	Propellant Weight (lbs)	Measurement Error (lbs)
1	44.5	0.5
2	47.0	0.5
3	47.5	0.5
4	52.0	0.5
5	35.5	0.5
6	34.5	0.5
7	47.0	0.5
8	52.5	0.5
9	54.5	0.5
10	37.0	0.5
11	49.0	0.5

Gross Weight	501.0	lbs
- Container Weight	-77.0	lbs
Net Weight	424.0	lbs
Error in Net Weight	18.4	lbs
Relative Error	4.3	%

Note: Net Weight is based on container weight of 7.0 ± 0.5 lbs.

Table G-II. Meteorological Data for 10/10/96

Ambient Temperature = 15°C
Dry Bulb Temperature = 16.1°C
Wet Bulb Temperature = 11.7°C
Wind Speed = 1.6 m/s
Wind Direction = 70°

Temp (°C)	Relative Altitude (m)	Absolute Altitude (m)	Temp (°F)	Balloon Altitude (ft)	Adiabatic Altitude (ft)
10.00	8.00	648.00	50.00	26.24	1666.67
9.00	155.00	795.00	48.20	508.40	2000.00
2.20	846.00	1486.00	35.96	2774.88	4266.67
-3.50	1543.00	2183.00	25.70	5061.04	6166.67
-1.30	1605.00	2245.00	29.66	5264.40	5433.33
-1.10	1667.00	2307.00	30.02	5467.76	5366.67
-5.70	2390.00	3030.00	21.74	7839.20	6900.00
-9.90	2941.00	3581.00	14.18	9646.48	8300.00
-12.10	3266.00	3906.00	10.22	10712.48	9033.33
-15.10	3614.00	4254.00	4.82	11853.92	10033.33
-20.90	4390.00	5030.00	-5.62	14399.20	11966.67
-21.10	4445.00	5085.00	-5.98	14579.60	12033.33
-20.70	4515.00	5155.00	-5.26	14809.20	11900.00
-21.30	4784.00	5424.00	-6.34	15691.52	12100.00
-22.50	4930.00	5570.00	-8.50	16170.40	12500.00

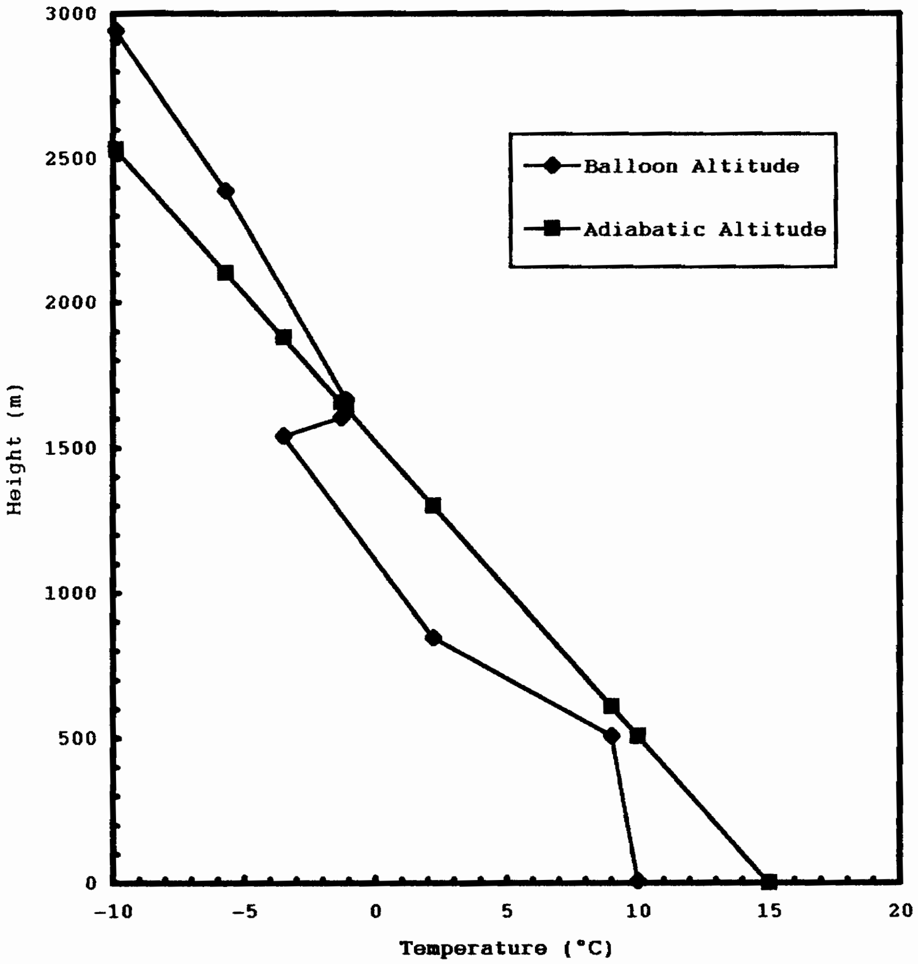

Figure G-1. Mixing Height Diagram for Burn #5 - 10/10/96

Note: Meteorological data from 7 PM balloon release at the National Weather Service station in Blacksburg.

Table G-III. Burn Duration Data for Burn #5 - 10/10/96

Test #	Burn Duration (sec)
1	16.37
2	16.41
3	16.28
4	16.43
5	16.31
6	16.40
7	16.28
8	16.41
9	16.47
10	16.50
Average =	16.39
Std Deviation =	0.08

Table G-IV. Velocity Profile Data for Burn #5 - 10/10/96

Reference Length: 4.27 ± .10m

Set #1 (4.27-8.54m Height)		Set #2 (8.54-12.81m Height)		Set #3 (12.81-17.08m Height)	
Test #	Time (s)	Test #	Time (s)	Test #	Time (s)
1	0.56	1	0.63	1	0.97
2	0.65	2	0.57	2	0.97
3	0.60	3	0.56	3	0.91
4	0.65	4	0.59	4	0.84
5	0.69	5	0.59	5	1.03
6	0.62	6	0.63	6	1.03
7	0.69	7	0.60	7	0.93
8	0.63	8	0.66	8	1.03
9	0.66	9	0.53	9	0.94
10	0.63	10	0.62	10	0.93
Average	0.64	Average	0.60	Average	0.96
Std. Dev.	0.04	Std. Dev.	0.04	Std. Dev.	0.06
Average Velocity =	6.69 m/s		7.14 m/s		4.46 m/s
Error =	0.17 m/s		0.18 m/s		0.12 m/s

Set #4 (17.08-21.35m Height)			Set #5 (21.35-25.62m Height)		
Test #	Time (s)		Test #	Time (s)	
1	0.94		1	0.85	
2	0.88		2	0.84	
3	0.85		3	0.94	
4	0.84		4	0.81	
5	0.82		5	0.97	
6	0.81		6	0.94	
7	0.78		7	0.91	
8	0.82		8	0.93	
9	0.78		9	1.03	
10	0.87		10	1.03	
Average	0.84		Average	0.93	
Std. Dev.	0.05		Std. Dev.	0.08	
Average Velocity =	5.09	m/s		4.62	m/s
Error =	0.13	m/s		0.14	m/s

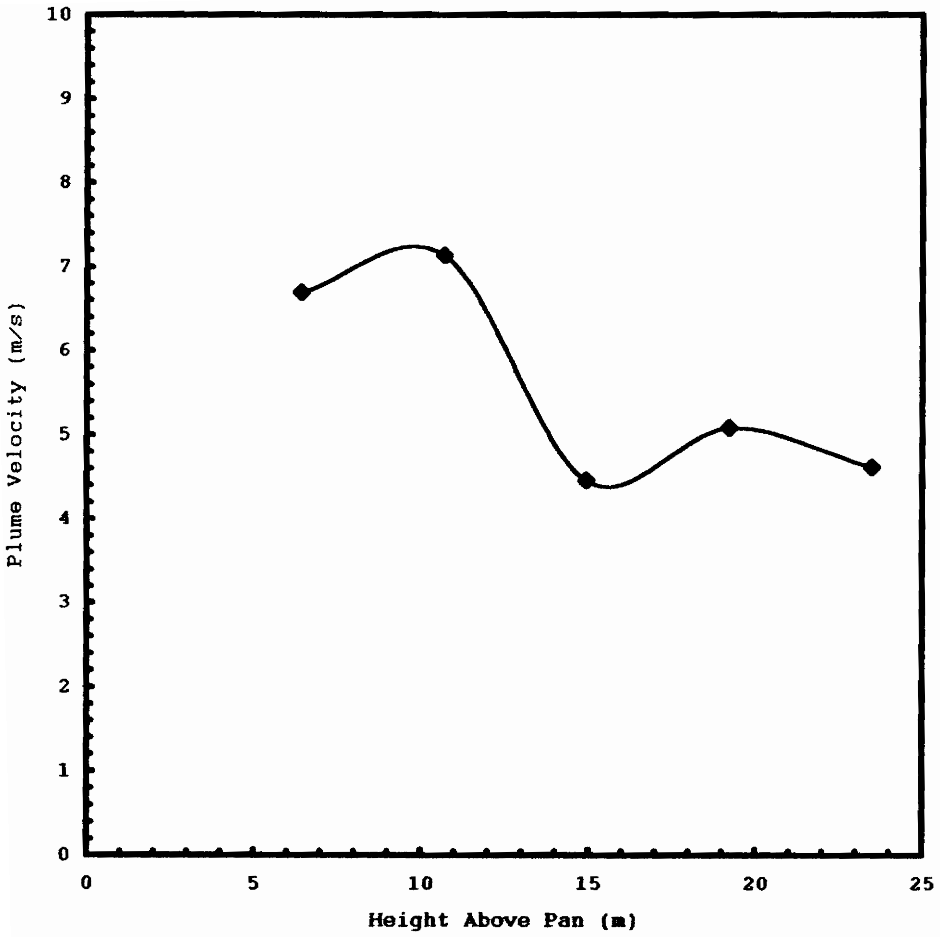

Figure G-2. Vertical Plume Velocity Profile for Burn #5 - 10/10/96

Appendix H.
Data from Burn #6 - 10/21/96

Table H-I. Propellant Weight Data for Burn #6 - 10/21/96

Container #	Propellant Weight (lbs)	Measurement Error (lbs)
1	57.0	0.5
2	68.5	0.5
3	57.0	0.5
4	49.0	0.5
5	57.5	0.5
6	48.0	0.5
7	39.5	0.5
8	69.0	0.5
9	49.0	0.5

Gross Weight	494.5	lbs
- Container Weight	-63	lbs
Net Weight	431.5	lbs
Error in Net Weight	16.29	lbs
Relative Error	3.78	%

Note: Net weight is based on container weight of 7.0 ± 0.5 lbs.

Table H-II. Meteorological Data for 10/21/96

Ambient Temperature = 17.8°C
Dry Bulb Temperature = 17.8°C
Wet Bulb Temperature = 12.2°C
Wind Speed = 0 m/s
Wind Direction = 0°

Maximum Surface Temperature: 19.40 °C
66.92 °F

Temp (°C)	Relative Altitude (m)	Absolute Altitude (m)	Temp (°F)	Balloon Altitude (ft)	Dry Adiabatic Altitude (ft)
15.00	8.00	648.00	59.00	26.24	1466.67
15.40	33.00	673.00	59.72	108.24	1333.33
14.60	143.00	783.00	58.28	469.04	1600.00
10.40	624.00	1264.00	50.72	2046.72	3000.00
8.80	850.00	1490.00	47.84	2788.00	3533.33
8.40	958.00	1598.00	47.12	3142.24	3666.67
8.00	1259.00	1899.00	46.40	4129.52	3800.00
8.00	1362.00	2002.00	46.40	4467.36	3800.00
9.00	1466.00	2106.00	48.20	4808.48	3466.67
1.20	2364.00	3004.00	34.16	7753.92	6066.67
1.60	2444.00	3084.00	34.88	8016.32	5933.33

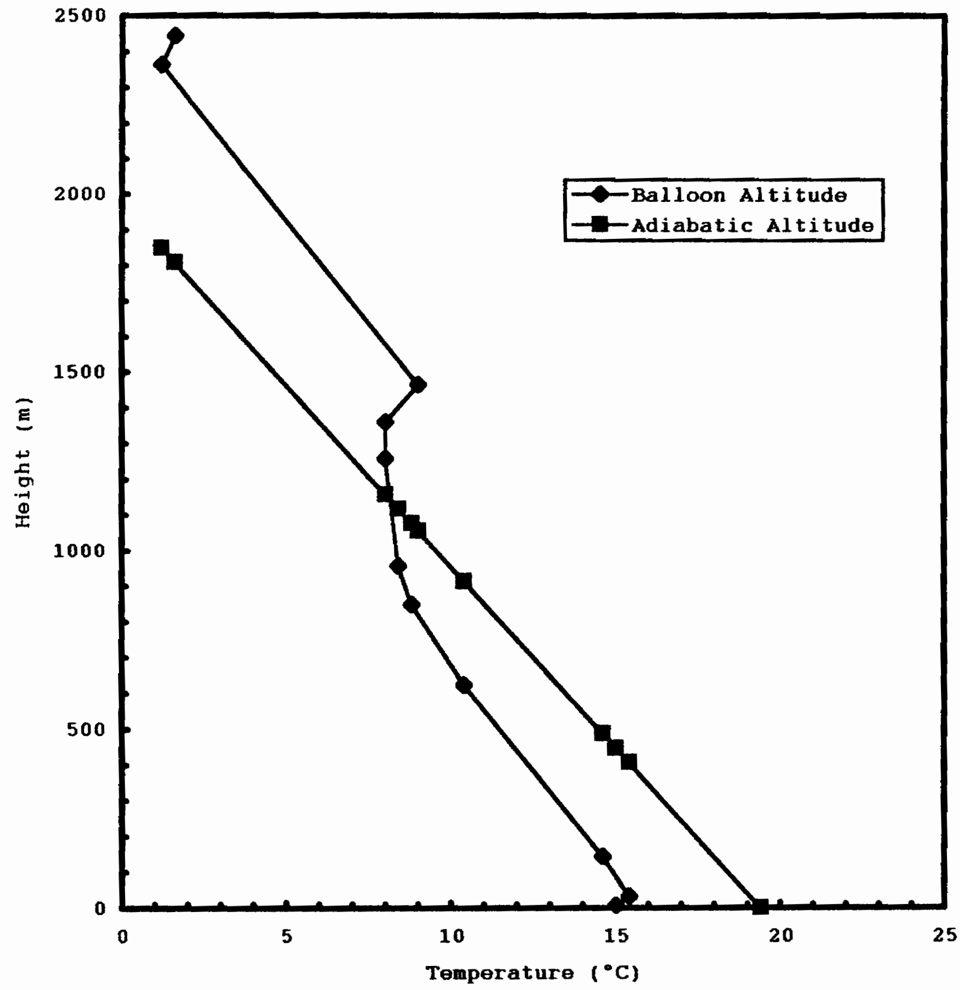

Figure H-1. Mixing Height Diagram for Burn #6 - 10/21/96

Note: Meteorological data from 7 PM balloon release at the National Weather Service station in Blacksburg.

Table H-III. Burn Duration Data for Burn #6 - 10/21/96

Test #	Burn Duration (sec)
1	16.72
2	17.50
3	17.25
4	17.00
5	16.94
6	16.97
7	17.62
8	17.72
9	17.47
10	17.88
Average	17.31
Std Deviation	0.39

Table H-IV. Velocity Profile Data for Burn #6 - 10/21/96

Reference Length: 4.27 +/- 0.10m

Set #1 (8.81-13.08m Height)			Set #2 (13.08-17.35m Height)			Set #3 (17.35-21.62m Height)	
Test #	Time (s)		Test #	Time (s)		Test #	Time (s)
1	0.81		1	0.63		1	0.50
2	0.91		2	0.69		2	0.59
3	0.85		3	0.59		3	0.53
4	0.91		4	0.60		4	0.60
5	0.85		5	0.66		5	0.62
6	0.75		6	0.72		6	0.53
7	0.84		7	0.68		7	0.59
8	0.81		8	0.65		8	0.53
9	0.94		9	0.60		9	0.56
10	0.85		10	0.59		10	0.53
Average	0.85		Average	0.64		Average	0.56
Std. Dev.	0.06		Std. Dev.	0.05		Std. Dev.	0.04
Average Velocity =	5.01	m/s		6.66	m/s		7.65 m/s
Error =	0.13	m/s		0.17	m/s		0.19 m/s

Set #4
(21.62-25.89m Height)

Test #	Time (s)
1	0.47
2	0.56
3	0.50
4	0.56
5	0.50
6	0.53
7	0.50
8	0.53
9	0.56
10	0.56
Average	0.53
Std. Dev.	0.03

Set #5
(25.89-30.16m Height)

Test #	Time (s)
1	0.53
2	0.63
3	0.60
4	0.60
5	0.56
6	0.50
7	0.60
8	0.59
9	0.56
10	0.50
Average	0.57
Std. Dev.	0.04

Average Velocity =	8.10	m/s	7.53	m/s
Error =	0.20	m/s	0.19	m/s

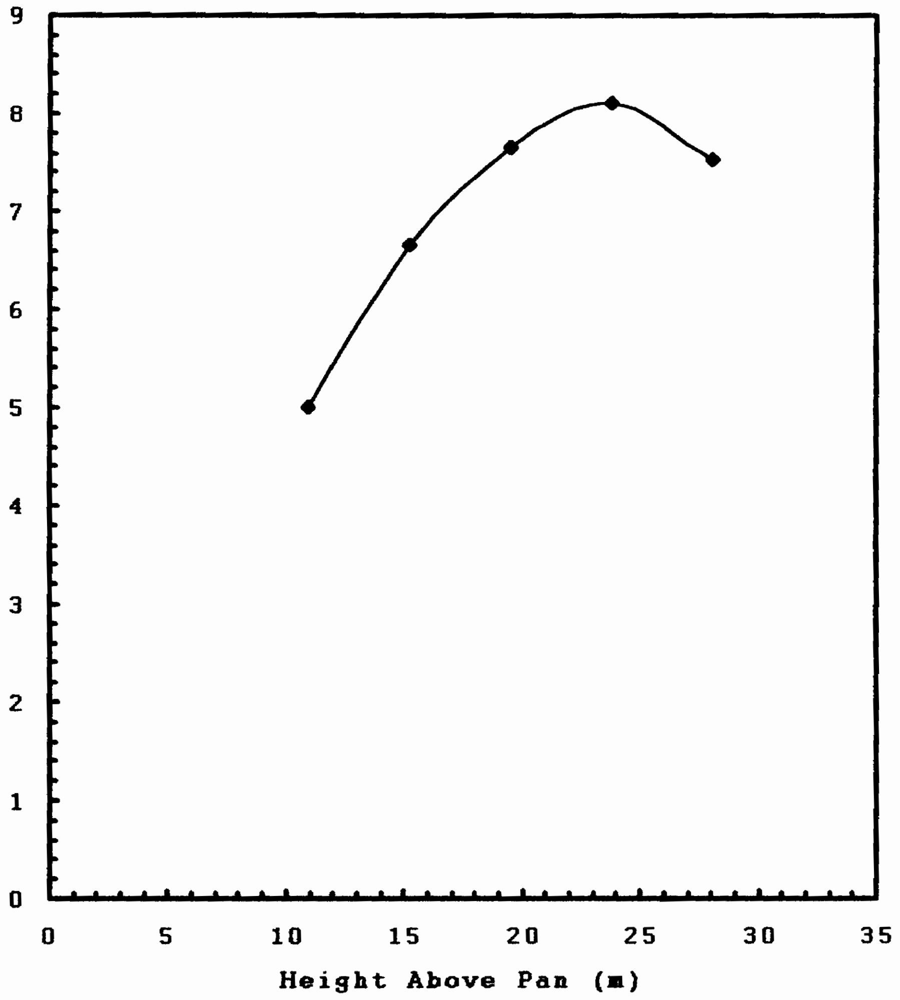

Figure H-2. Vertical Plume Velocity
Profile for Burn #6 - 10/21/96

Appendix I.
Data from Burn #7 - 10/31/96

Table I-I. Propellant Weight Data for Burn #7 - 10/31/96

Container #	Propellant Weight (lbs)	Measurement Error (lbs)
1	57.5	0.5
2	58.0	0.5
3	57.5	0.5
4	57.5	0.5
5	58.0	0.5
6	67.5	0.5
7	58.0	0.5
8	68.0	0.5

Gross Weight	482.0	lbs
- Container Weight	-56.0	lbs
Net Weight	426.0	lbs
Error in Net Weight	15.25	lbs
Relative Error	3.58	%

Note: Net weight is based on container weight of 7.0 ± 0.5 lbs.

Table I-II. Meteorological Data for 10/31/96

Ambient Temperature = 20°C
Dry Bulb Temperature = 20.6°C
Wet Bulb Temperature = 13.3°C
Wind Speed = 5.1 m/s
Wind Direction = 55-70°

Maximum Surface Temperature: 20 °C
68 °F

Temp (°C)	Relative Altitude (m)	Absolute Altitude (m)	Temp (°F)	Balloon Altitude (ft)	Adiabatic Altitude (ft)
16	8	648	60.8	26.24	1333.33
14.4	141	781	57.92	462.48	1866.67
8.8	848	1488	47.84	2781.44	3733.33
3	2429	3069	37.4	7967.12	5666.67
-11.7	5080	5720	10.94	16662.4	10566.67
-24.3	6750	7390	-11.74	22140	14766.67
-38.5	8800	9440	-37.3	28864	19500
-50.1	10020	10660	-58.18	32865.6	23366.67
-57.9	11450	12090	-72.22	37556	25966.67
-64.5	13240	13880	-84.1	43427.2	28166.67
-66.1	15680	16320	-86.98	51430.4	28700

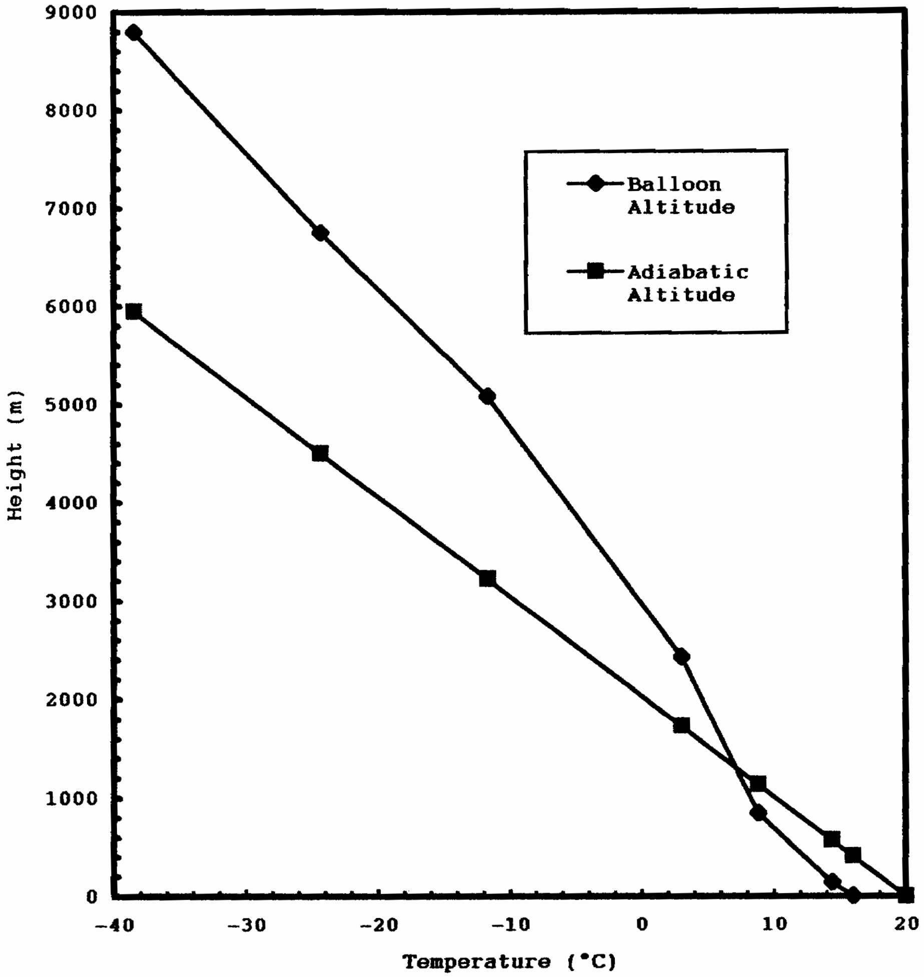

Figure I-1. Mixing Height Diagram for Burn #7 - 10/31/96

Note: Meteorological data from 7 PM balloon release at the National Weather Service station in Blacksburg.

Vita

James Phipps was born on April 9, 1972 in Lexington, VA. He completed his high school education at Lee High School in Ben Hur, VA. He received his Bachelor's degree in Chemical Engineering from Virginia Polytechnic Institute and State University in 1994.

James is currently completing his Master's degree in Environmental Engineering, specializing in air pollution control and hazardous waste management.

James F. Phipps