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MONITORING OF GASES FROM EXPLOSIVES DETONATED IN AN UNDERGROUND MINE

Bureau of Mines Open File Report 72-83

Contract H0395098
Department of Mining and Geological Engineering
College of Mines
University of Arizona

BUREAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR
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Toxic gases	Products of detonation	Carbon monoxide	
Toxic gas production	Nitric oxide	Sulfur dioxide	

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FORWARD

This report was prepared by the Department of Mining and Geological Engineering, College of Mines, University of Arizona, Tucson, Arizona 85721 under USBM Contract Number H0395098. The contract was initiated under the Minerals Health and Safety Technology program. It was administered under the technical direction of the Pittsburgh Research Center of the Bureau of Mines with Mr. T. Christos acting as Technical Project Officer. Mr. W. R. Mundorf was the Contract Administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period August 10, 1979 to June 30, 1982. This report was submitted by the authors on June 30, 1982.

In view of the nature of the work performed, no patentable inventions were made under this project.

The authors express their appreciation to the many individuals involved with the actual mining operations and analytical procedures required to conduct this research. Special recognition is extended to Abdulla Arik, A. J. Gaudielle, Charles Smith and Randall Thomas, of the Department of Mining and Geological Engineering for their devoted attention to this project.

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ABSTRACT

The concentration of six different gases produced by the detonation of four explosives was measured in a dry underground metal mine during actual mining operations. The four explosives included one semigelatin dynamite, one gelatin dynamite and two water gel explosives. A standard drill pattern was used to detonate the explosives as a full-face round in the drift. The gases released by the explosion were trapped in the drift, a test chamber created by a bulkhead located at the entry of the drift. The concentration of the gases in the test chamber were measured by direct readout instruments. The average volume of each gas per pound of explosive detonated (ft^3/lb) was found to occur in the following ranges: NO, 0.04-0.14; NO_2, 0.03-0.10; CO, 0.08-0.45; SO_2, 0.001-0.006; NH_3, 0.003-0.027; and CO_2, 1.82-7.02.

INTRODUCTION

Background

Materials used for blasting in underground mining operations produce a variety of gases, in varying concentrations, depending upon the composition and characteristics of the agent. Personnel exposed to these gases may experience deleterious health effects if exposure is prolonged and/or if the gases exceed certain concentration levels. For this reason, explosive experts have been conducting research to determine the types and amounts of gases produced by the detonation of explosives.

Studies to characterize the gases produced by explosives began in laboratories more than fifty years ago. The well known Bichel gage (1) and the Crawshaw-Jones apparatus (2) were developed early in the centry. These testing devices consisted basically of a closed chamber in which the explosives were detonated and the gases produced were identified and measured by standard laboratory techniques. However, it was recognized that tests in artifical environments did not accurately reflect the gas production from detonation of explosives in an underground environment (2). As a result, a number of researchers initiated studies concerning production of gases under actual mining conditions. In 1925, Gardner, Jones, and Sullivan (4) sampled the gases produced during blasting in massive sulfides. From their study they concluded that: 1) large amounts of sulfur dioxide may be generated while blasting in heavy sulfide ore, particularly in dry working places where dust had settled on the walls and 2) the amount of hydrogen sulfide produced was increased by water in drill holes. In 1927, Gardner, Howell, and Jones (5) conducted an extensive field study at five metal mines to collect and analyze gases from explosives detonated during actual underground mining operations. The investigation demonstrated that the age and condition of an explosive may influence the relative amounts of gases produced. In addition, it was found that the concentration of gases produced when the drill hole was stemmed was less than when there was no stemming.

Several years later, in an investigation at the Bureau of Mines' laboratory, Tiffany, Murphy, and Hanna (12) measured gases from explosives detonated in the Bichel gage and compared them with the results obtained in underground mine tests in an effort to evaluate the validity of laboratory measurements. They found that the results from the Bichel gage could not be used to predict with certainty the quantity of gases that would be in the mine atmosphere at the working face.

Similarly, Van Dolah, Murphy, and Hanna (14) investigated gas production from ANFO explosives. Their studies involved both laboratory work at the Bureau of Mines' laboratory using Crawshaw-Jones apparatus and field work in an underground mine. Results of these studies led to the following general conclusions: 1) the quantity of fumes from ANFO explosives was dependent upon

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Underlined numbers in parentheses refer to items in the list of references at the end of this report.

composition, moisture and intensity of initiation, and 2) dry, well mixed, oxygen balanced ANFO mixtures initiated by a strong primer produced oxides of nitrogen in quantities comparable to commercial dynamite.

Recently, during 1975-1977, measurement of gases produced by explosives were obtained in two separate investigations by Rodgers, et. al., (8, 9) under contract with the U. S. Bureau of Mines. In the first study (8), measurements were made from actual production shots at two underground mines and in the Bureau of Mines' 1350 ft^3 test chamber. Gas measurements at the mines were made by supplying the face with fresh air after the shot and continuously analyzing the return air. It was found that the amounts of carbon monoxide and oxides of nitrogen produced per unit weight of ANFO mixtures and water gel explosives were less than that produced by nitroglycerin explosives. In the second study (9), the blast gases were retained in the drift by a brattice curtain located about 60 feet from the face. The results of this study showed that water gel explosives produced less carbon monoxide than nitroglycerin-based explosives.

A recent study on the production of gases from explosives was completed by a research team from Michigan Technological University (MTU) in 1978 (7). They investigated gas production from six explosives at MTU's Experimental Mine under contract with the U.S. Bureau of Mines. They found an "apparent" correlation between the production of gas and their respective energy densities. They also found a decrease in gas production with increasing mass of explosive in three out of four of the scaled studies. However, they could not obtain meaningful data from measurements of oxides of nitrogen because they appeared to be readily absorbed by the wet walls of the mine before the measurements could take place. Hence, in 1979, the USBM made a contract for a similar research with the University of Arizona that proposed to test the explosives in a "dry" mine (13).

The University of Arizona, through the Department of Mining and Geological Engineering, undertook the task of measuring the volume of six specific gases (NO, NO_2, CO, CO_2, SO_2 and NH_3) generated by the detonation of known amounts (by weight) of explosives in an actual underground mining environment. The work was conducted at the University's San Xavier Mine Laboratory. This mine laboratory was particulary suited for the study because it is dry. This study is the first of its kind in this mine and the experiments were designed to satisfy the requirements of the U. S. Bureau of Mines' Contract No. H0395098.

The gases produced by detonation of the explosives were contained in a test chamber created by closing and sealing the door at a bulkhead constructed at the entry of the mine drift. The gases were mixed in the chamber by recirculating the air with a blower located in the drift. The mine atmosphere was sampled by remote means and the gases were analyzed using an infrared spectrometer for CO, CO_2, SO_2 and NH_3 and a chemiluminescence instrument for NO and NO_2.

Project Objectives

The primary objective of this study was "to determine the identity and quantity of toxic gases evolved on shotfiring explosives in an underground mine."

Initially, the scope of the work to be performed required that six explosives, selected in consultation with the technical project officer, be tested. This requirement was later amended to four explosives. For each explosive, eight successful blasts were used for the purpose of measuring the concentration of the gases (CO, CO_2, NO, NO_2, SO_2 and NH_3) produced and calculating the volume of each gas produced by a unit mass of explosive.

The secondary objective of the study was "to determine the effect of explosive mass on the production of toxic gases." This determination was made by conducting scaling tests for two of the four explosives used. This required a series of nine shots of varying mass of explosive. The volume of gas produced per unit mass of explosive was calculated from these tests.

Scope of Presentation

A detailed description of the work performed in this study will be as follows: the introductory section provides the background and objectives of the study; the second section describes the explosives selected; the mine laboratory and experimental procedures used to generate the gases and the procedures used to determine the amount of gas produced by the explosives are described in the third section; the results of the tests are given in the fourth section; and the last section is devoted to the discussion of results and presentation of conclusions.

EXPLOSIVES TESTED

Selection of Explosives

Four explosives were selected for the tests with the approval of Mr. T. Christos, Technical Project Officer, and were of the following types: two water gel explosives, one gelatin dynamite and one semigelatin dynamite. Six hundred fifty pounds of each explosive, of the same lot, were purchased; one hundred prounds were delivered to the Pittsburgh Research Center for testing in their laboratory and 550 pounds were designated for use in the tests conducted at the San Xavier Mine Laboratory. All of the explosives were of the nonpermissible type and classified as Class A high explosives. Table 1 identifies the explosives used and Table 2 lists some of the pertinent characteristics of each explosive.

General Information (15)

The distinction between an explosive and a blasting agent is their cap-sensitive characteristics. An explosive can be detonated by a No. 8 blasting cap and a blasting agent cannot. Blasting agents require a cap-sensitive primer or primer-booster for detonation. Blasting agents are, therefore, the safest to handle of the materials available for blasting purposes.

Materials classified as explosives may contain nitroglycerin or nitroglycerin and ethylene glycol dinitrate in varying amounts. Those materials that do not contain nitroglycerin but which are classified as explosives may contain any one of a variety of explosive sensitizers, such as TNT, as well as varying amounts of inorganic salts, fuels and thickening agents. Explosives include materials designated as straight dynamite, ammonium dynamite, gelatin dynamite, ammonia-gelatin dynamite, semigelatin dynamite, blasting gelatin, nitrostarch explosive and water gel explosive.

A very important property of the explosive selected should be its fuming characteristics if the explosive is to be used in underground mining operations. Its fuming characteristic refers to the volume of gaseous by-products released at detonation. The amount of gases produced depend largely on the ratio of carbonaceous ingredients to the salts that furnish oxygen for combustion. For example, if available oxygen is insufficient, carbon monoxide, in higher concentration, is produced; an over abundance of oxygen results in the generation of a higher volume of oxides of nitrogen. The production of gaseous by-products depends also on the completeness of detonation; a low-order detonation may produce excessive amounts of toxic gases. For nonpermissible explosives, fume classifications by the Institute of Makers of Explosives are based on the number of cubic feet of gas produced by a 1 1/4 x 8-in cartridge when detonated in the Bichel Gauge. The classes are: Class 1 - less than 0.16 cu ft; Class 2 - 0.16 to 0.33 cu ft; Class 3 - 0.323 to 0.67 cu ft.

Table 1. Explosives Selected For Testing*

Manufacturer	Explosive	Supplier	**Cost/100 lbs
Ireco Chemical	Iremite 40	Ireco Chemical 923 S. Palo Verde St. Mesa, AZ 85708	$67.75
Apache Power Co.	Amogel No. 3	Apache Powder Co. P. O. Box 700 Benson, AZ 85602	$62.00
Apache Power Co.	Dynagel 205	Apache Powder Co. P. O. Box 700 Benson, AZ 85602	$62.50
Apache Power Co.	40% Special Gelatin	Apache Powder Co. P. O. Box 700 Benson, AZ 85602	$75.00

*Reference to specific brands, equipment, or trade names in this document is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

**As of the date of purchase: Iremite 40 on 4/17/80, Amogel No. 3 on 2/8/80, Dynagel 205 on 2/8/80 and 40% Special Gelatin on 5/22/81.

Table 2. Characteristics of Explosives

Explosive	Type	Cartridge		
		Size (inches)	Construction of Casing	Number per 50 lb Case
Iremite 40	water gel explosive	1 1/4 x 16	mylar/polyethylene	62
Amogel No. 3	Semigelatin dynamite*	1 1/4 x 8	waxed paper	120
Dynagel 205	Water gel explosive	1 1/4 x 12	mylar/polyethylene	86
40% Special Gelatin	gelatin dynamite*	1 1/4 x 8	waxed paper	94

* Contain nitroglycerin

In general, the following fuming characteristics of explosives are observed: straight dynamite - poor and not recommended for underground or confined spaces; gelatin dynamite - poor for higher strengths and good for lower strengths; ammonia-gelatin dynamite - generally good in all strengths; semigelatin dynamite - good; blasting gelatin - poor due to high nitroglycerin content; and water gel explosive - good.

Explosives are given a "class" designation for the purpose of compliance with transportation regulations. Class A explosives represent a detonating hazard while Class B present, principally, a fire hazard.

The brisance (shattering or fragmentation effect) of an explosive is determined by its density and detonation velocity. A high density explosive usually has a corresponding high detonation velocity. In hardrock mining an explosive with high detonation velocity is desirable.

EXPERIMENTAL DESIGN AND TEST PROCEDURE

San Xavier Mine Laboratory

General Description

The San Xavier Mine Laboratory, formerly known as the San Xavier Mine - No. 6 Shaft, is located approximately 23 miles south of Tucson, Arizona in the Pima Mining District. Access from Tucson may be gained by traveling south on Mission Road or by traveling south on the interstate freeway, I-19, to the Valencia Road Exit going west and then south on Mission Road (Figure 1).

The San Xavier No. 6 shaft and related development of about 2,500 feet of underground drifts (4 x 6 ft) were first leased by the University of Arizona, College of Mines in November, 1958. The purpose was to provide a laboratory for students enrolled in mine surveying and geologic mapping. In the early 1970's the mining engineering students and some faculty members became interested in having a "school mine" that was operational and could provide "hands on" mining experiences. This interest led to a proposal for funding from the University and from the mining industry. The mining industry's response was strongly supportive and Anamax Mining Company, with the approval of the Board of Regents, donated two mining claims together with all of the underground development in these claims to the Univeristy of Arizona in September, 1975.

With volunteer student and faculty effort, donations from various mining companies and professional organizations and support from the College of Mines, the mining laboratory has been transformed to a viable training and research facility. Additional work is planned that will further expand the usefulness of the laboratory.

The San Xavier Mine Laboratory (SXML) has a shaft extending to a depth of 250 feet to service the two working levels, however, it has only been refurbished to a depth of 150 feet. The 100 level communicates with the 150 level via the manway in the shaft and the "Long Raise." An adit level has been enlarged from a 4 x 6 ft opening to an 8 x 8 ft drift, suitable for mechanized equipment, and communicates with the 100 level via the "Corkscrew Raise."

Ventilation to the 100 and 150 levels can be maintained either by natural ventilation or by use of a 10 HP fan with a rated volume of 10,000 cfm. The fan is located on the surface and can function either downcast or upcast. The ventilation raise connects with the "Corkscrew Raise" and by use of ventilation doors in the raise and adit, the fan can be used to ventilate either the adit level or the other two levels.

Figure 2 shows a plan and section view of the adit and adit turnout at the time this study was begun and Figure 3 is a map showing the topographic characteristics of the mine property and the location of mine surface facilities.

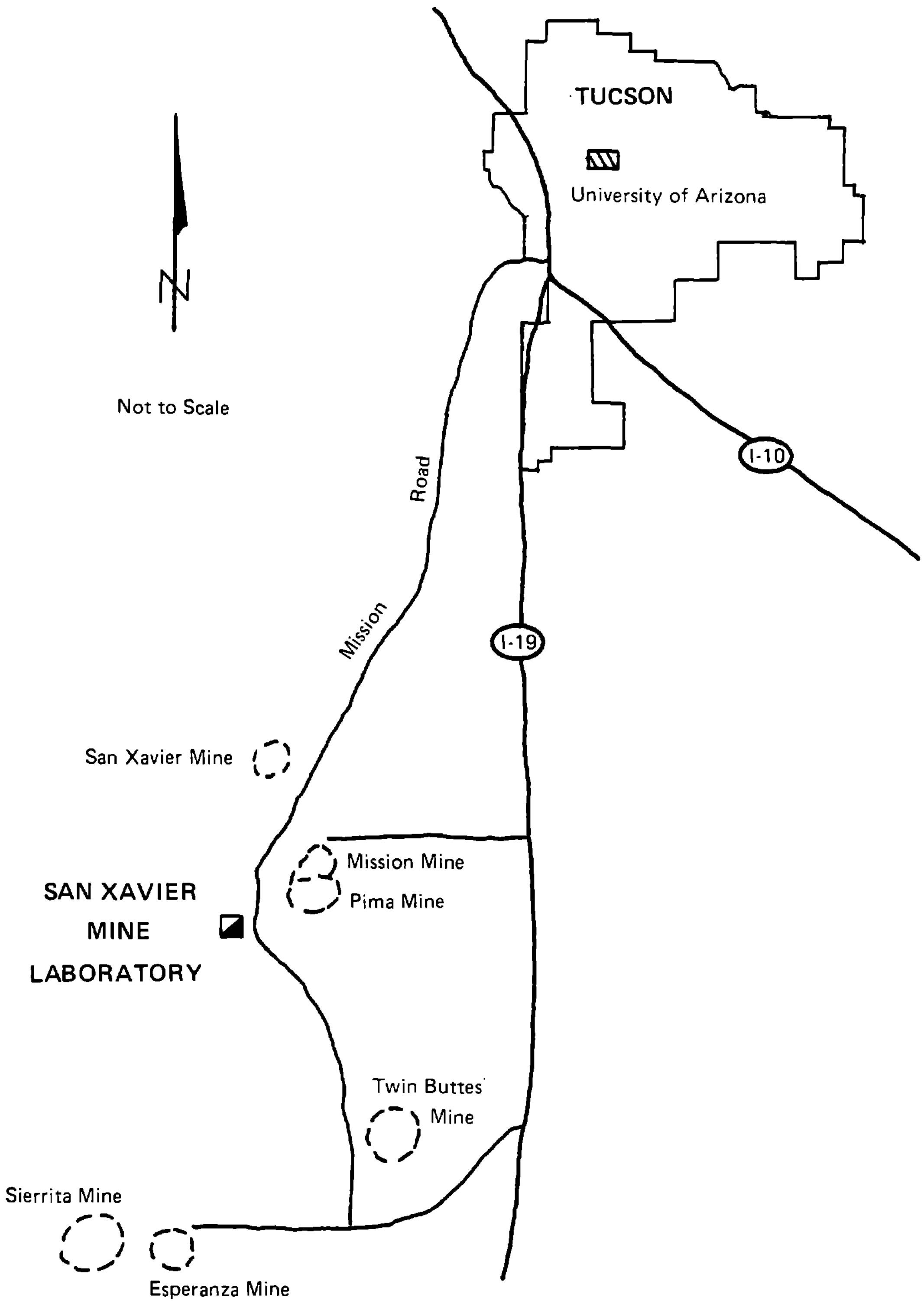


Figure 1. Geographical Location of San Xavier Mine Laboratory

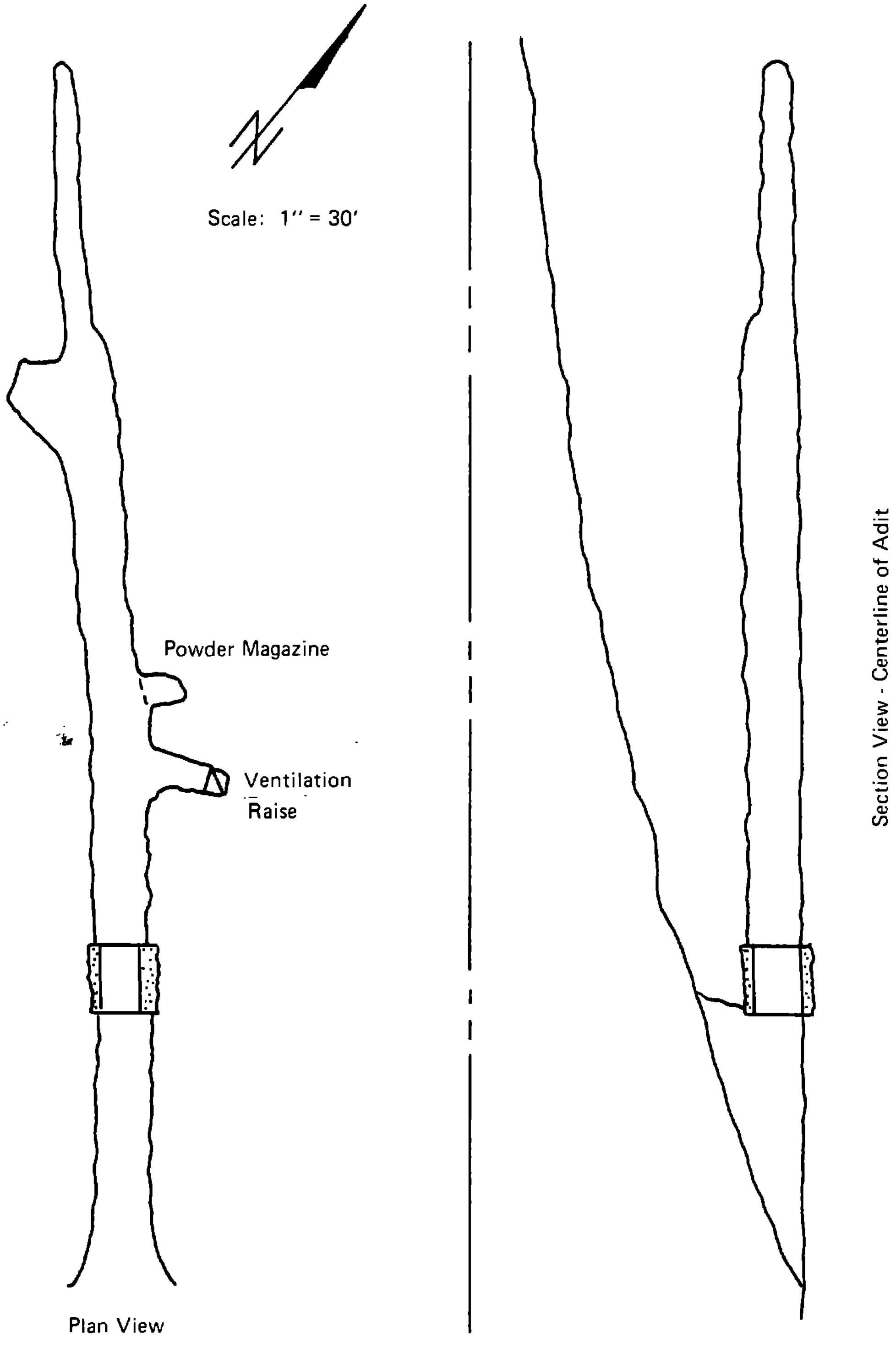


Figure 2. Plan and Section Views of SXML Adit Level

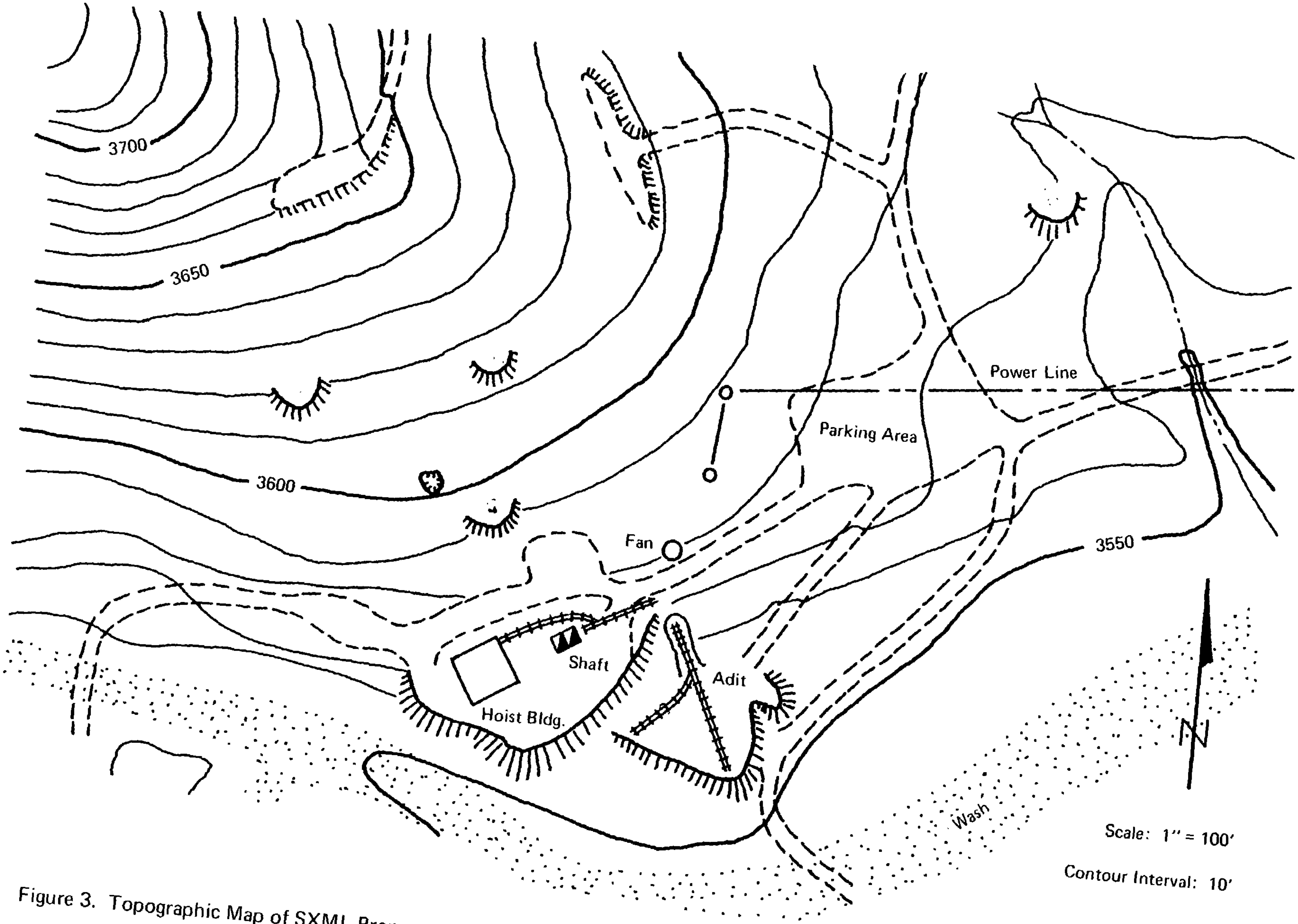


Figure 3. Topographic Map of SXML Property

Geology (16)

The SXML is situated in a group of small hills rising steeply from the alluvial plain. The surface rocks are mainly of sedimentary origin. Limestones of various ages comprise most of the exposed sedimentary rock with some quartzite and shale also being present. The sedimentary rocks rest upon coarse textured, intrusive, igneous rocks, mainly granite (crystalline igneous rock of quartz, orthoclase, with both muscovite and biotite) and granodiorite. In places, porphyry (rock consisting of feldspar crystals embedded in a compact dark red or purple groundmass) dikes cut through the sedimentaries. The mine workings are in the limestone sedimentaries where the mineralization occurred. Galena (PbS), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), and pyrite (FeS_2) were the major minerals extracted and occurred in small and discontinuous ore bodies.

Description of Test Chamber

The experimental work performed under this contract was carried out in the adit level. Initially two test chambers were to be established to expedite the testing; one chamber in the main drift and one in the adit turnout. Work in the main drift was to include enlargement of the existing 4 x 5 ft drift and placement of a bulkhead to create one of the test chambers. Unfortunately, work had to be stopped due to badly fractured ground; the fractures became sources of leakage to the surface. Extensive drift development would have been required to pass through this highly fractured zone. The ground in the adit turnout was well suited for the test chamber. Figure 4 shows the extent of work completed during this project.

A bulkhead was constructed in the adit turnout approximately 15 ft from the centerline of main drift. It was constructed of 4 x 6 in posts and 2 x 8 in lagging. The openings between the lagging and openings around the periphery of the bulkhead were sealed with caulking material. Expanded metal lathing was used to cover the bulkhead and a fibrous cement material was used to plaster the bulkhead suface on the side of the chamber. A 5 x 7 ft door, constructed from 5/8 in thick plywood, was attached at the top of the bulkhead and suspended so that it could be dropped in place from a remote location to close the opening after the blast occurred. An adequate seal was maintained around the door by use of weather stripping and locks at the bottom of the door. Visual checks and gas detection tests at the bulkhead verified that leakage was practically eliminated.

To assure that the gases generated by the detonation of the explosive became thoroughly mixed within the chamber, a mobile 5 HP fan was brought into the chamber prior to each test for the purpose of recirculating the air within the chamber. The fan was attached to the ventilation duct via flexible ventilation tube to a T-connection, and with appropriately placed blast gates an air recirculating system was created. Following each blast, the fan was turned-on from a remote location after the door at the bulkhead had been secured in a closed position.

The air samples from the test chamber were drawn at a rate of approximately 2 cubic feet per minute by a vacuum pump through a 225 ft long, 0.5 in diameter Teflon tube to the hoist house where the analytical instruments were located. The intake of the sampling tube was located 15 ft

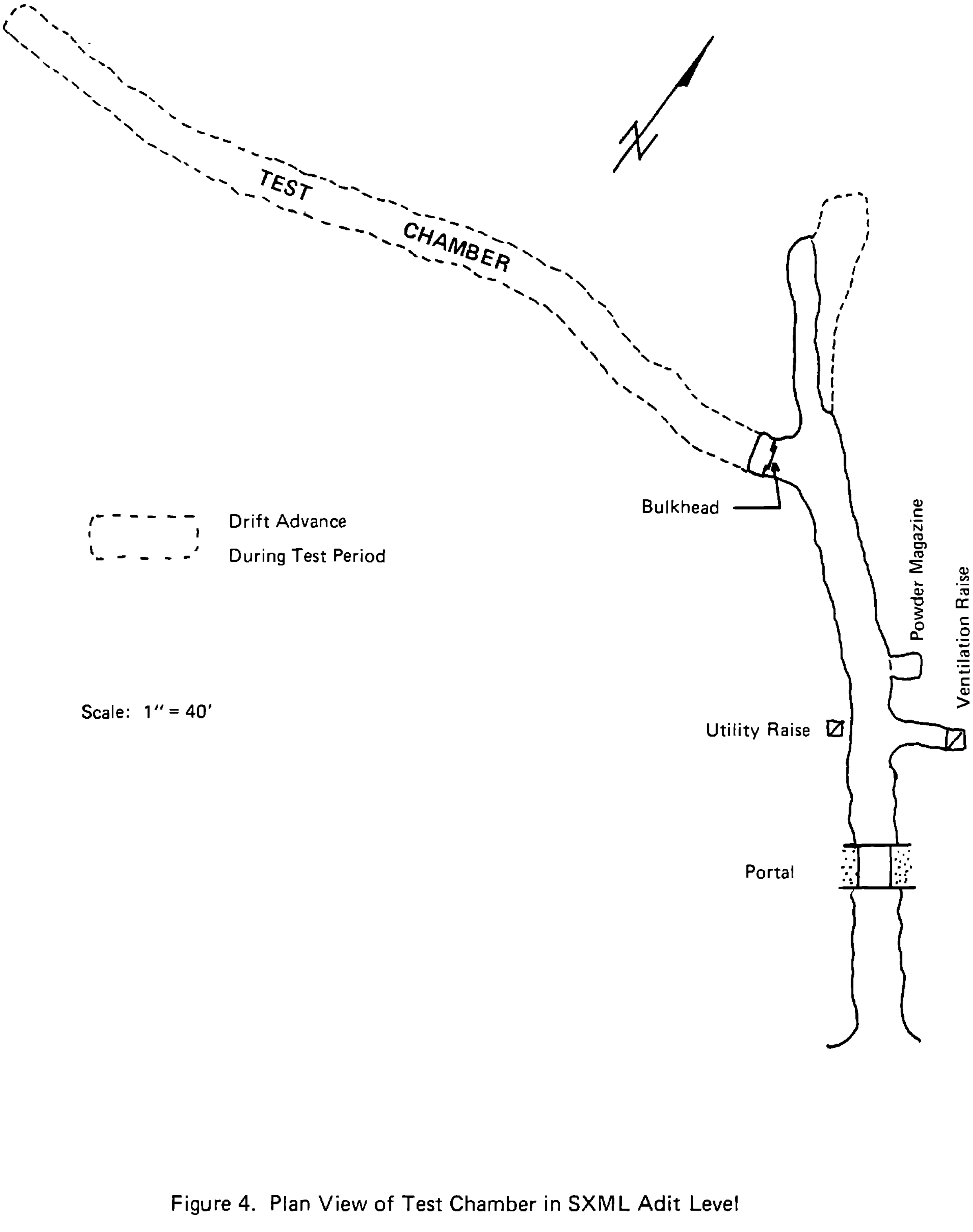


Figure 4. Plan View of Test Chamber in SXML Adit Level

inside the chamber, approximately 4 ft above the floor, and 2 ft from the drift wall. The intake was equipped with a large glass fiber filter to remove airborne dust and was changed after each test.

Figure 5 is a sketch of the adit turnout showing the location of the bulkhead, the air sampling line and the air recirculation system.

The drill pattern to advance the drift selected for this experiment was the San Xavier Mine standard drill round (Figure 6). This pattern requires a burn hole and 25 holes for the explosive. The blast was executed by using 8 delays. The number of sticks of explosives used differed for each explosive but the amount of explosive used in each of the eight blasts with the same type of explosive remained essentially the same. The explosive was tamped in the holes and detonated with nonelectric delay caps. The holes were not stemmed. Table 3 shows the order of the explosives tested and the amount of explosive detonated in each blast.

Measurement of Test Chamber Volume

The volume of the test chamber was determined by two methods: 1) by physical measurements in the drift and 2) by CO_2 dilution measurements in the drift. Good correlation was obtained between these two methods of measurement (Table 4).

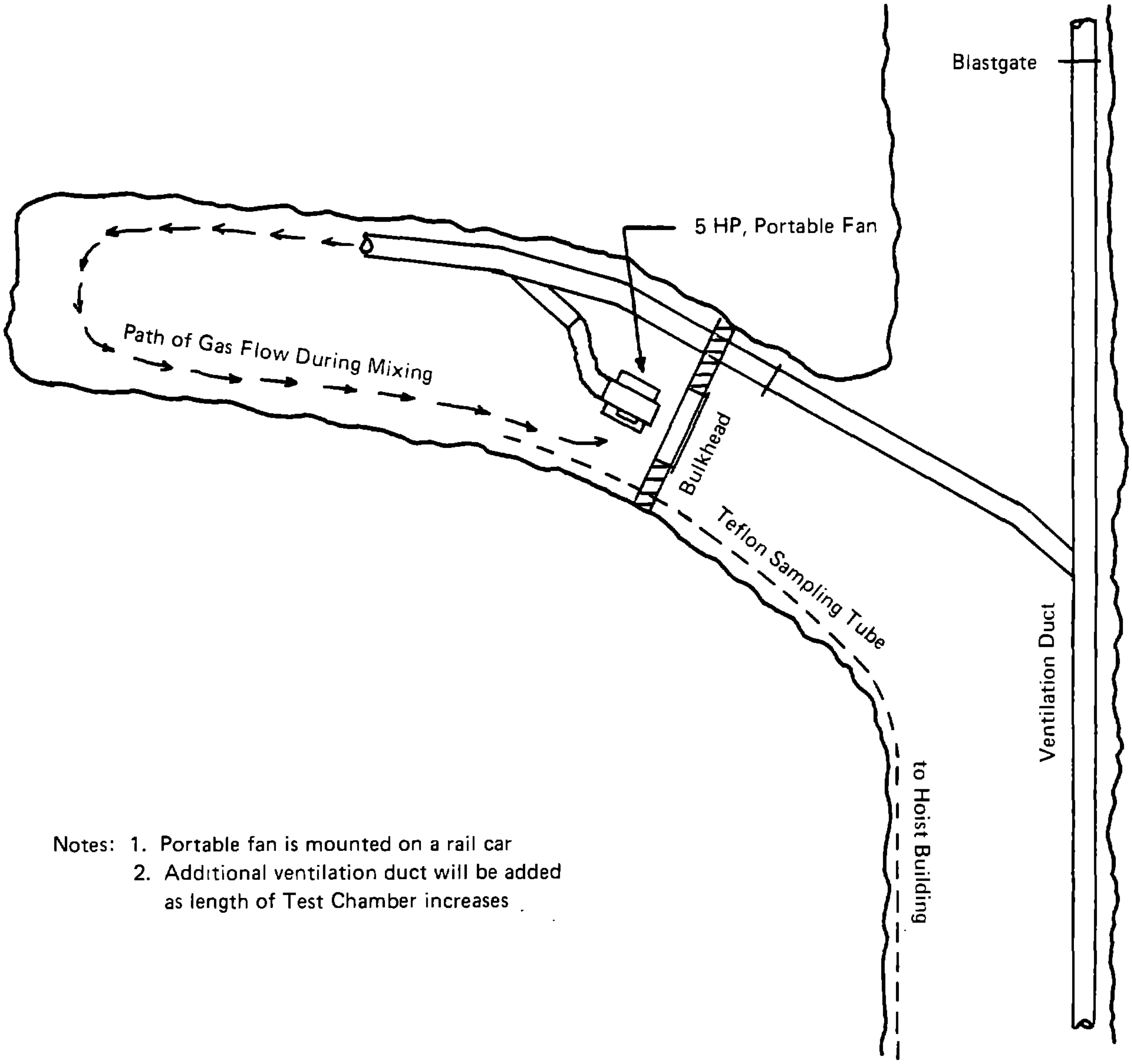
Figure 7 shows the method used to calculate the cross-sectional area of the drift at any point by physical measurement. Two cross-sectional configurations are used; System I overestimates the area and System II underestimates the area. The average of the two systems provides an acceptable value. The drift or containment is further divided into sections of the desired depth and the volume of each section is calculated by multiplying the depth by the area of each section. The total volume of the containment is the sum of all the sections.

To determine the volume of the containment or test chamber by the CO_2 dilution method, a known mass of CO_2 was released in the chamber and mixed to assure a homogeneous concentration. The air was then sampled and analyzed with the Miran-80 to determine its concentration. The volume of the chamber was calculated by using the following expression:

$$V = \frac{W \times 5.094 \times 10^5}{8079 \times 10^{A_1} - 5338 \times 10^{A_2} - 3431}$$

where: V is the chamber volume in cubic meters
W is the weight of gas(CO_2) released into the chamber in Kilograms (kg)
A_1 is the absorbance value at wavelength, $\lambda = 4.278\mu m$
A_2 is the background absorbance at the same wavelength

The equation was derived empirically from laboratory calibrations using known concentrations of CO_2 and water vapor.



Notes: 1. Portable fan is mounted on a rail car
2. Additional ventilation duct will be added as length of Test Chamber increases

Figure 5. Plan View of Adit Turnout Showing Test Chamber Detail

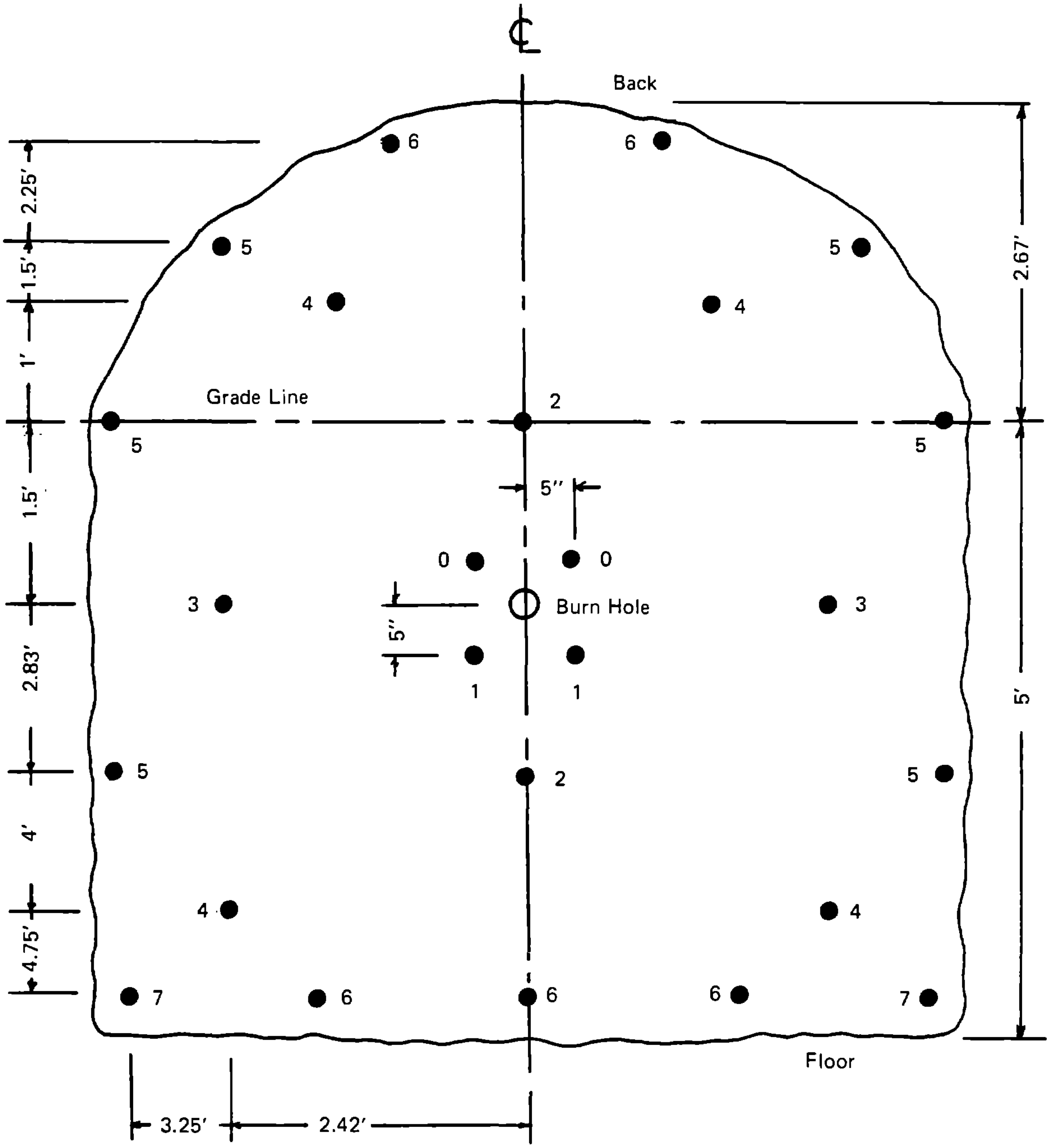


Figure 6. View of Drift Face Showing Standard Drill Round and Detonation Delay Sequence

Table 3. Firing Order of Explosives and Amount of Explosives Detonated

Explosive		Experiment	Number of			Mass Detonated	Comment
No.	Designation	No.	Holes Loaded	Sticks Used	Sticks Detonated	(lbs)	
1	Iremite 40	1	4	12	12	9.48	Scaling test
		2	2	3	3	2.37	" "
		3	2	4	4	3.16	Scaling test, bootlegged both holes
		3a	2	6	6	4.74	Scaling test, same hole as #3 above
		4	2	6	6	4.74	Scaling test
		5	2	4	4	3.16	" "
		6	3	9	9	7.11	" "
		7	3	10	10	7.90	" "
		8	2	6	6	4.74	" "
		9	25	67	67	52.93	Full face shot
		10	25	67	67	52.93	" " "
		11	25	67	64	50.96	Full Face shot, 3 sticks did not detonate
		12	25	67	67	52.93	Full face shot
		13	25	67	67	52.93	" " "
		14	25	67	67	52.93	" " "
		15	25	67	67	52.93	" " "
		16	25	67	67	52.93	" " "

Table 3. Firing Order of Explosives and Amount of Explosives Detonated (continued)

Explosive		Experiment	Number of			Mass Detonated	Comment
No.	Designation	No.	Holes Loaded	Sticks Used	Sticks Detonated	(lbs)	
2	Amogel No. 3	17	4	24	24	10.08	Scaling test
		18	2	12	12	5.04	" "
		19	2	12	12	5.04	Scaling test, bootlegged one hole
		20	2	12	12	5.04	Scaling test, same hole missed #19 above
		21	2	12	12	5.04	Scaling test
		22	2	11	11	4.62	" "
		23	6	30	30	12.60	" "
		24	2	8	8	3.36	" "
		25	3	24	24	10.08	Scaling test
		26	25	141	141	59.22	Full face shot
		27	25	144	144	60.48	" " "
		28	25	138	138	57.96	" " "
		29	25	143	141	59.22	Full face shot, 2 sticks did not detonate
		30	25	139	139	58.38	Full face shot
		31	25	139	135	56.70	Full face shot, 4 sticks did not detonate
		32	25	142	142	59.64	Full face shot
		41	25	132	132	55.44	" " "

Table 3. Firing Order of Explosives and Amount of Explosives Detonated (continued)

Explosive		Experiment	Number of			Mass Detonated	Comment
No.	Designation	No.	Holes Loaded	Sticks Used	Sticks Detonated	(lbs)	
3	Dynagel 205	33	25	94	94	56.40	Full face shot
		34	25	100	100	60.00	" " "
		35	25	102	102	61.20	" " "
		36	25	93	93	55.80	" " "
		37	25	94	92	55.20	Full face shot, 2 sticks did not detonate
		38	25	100	98	58.80	Full face shot, 2 sticks did not detonate
		39	25	96	93	55.80	Full face shot, 3 sticks did not detonate
		40	25	99	99	59.60	Full face shot

Table 3. Firing Order of Explosives and Amount of Explosives Detonated (continued)

Explosive		Experiment	Number of			Mass Detonated	Comment
No.	Designation	No.	Holes Loaded	Sticks Used	Sticks Detonated	(lbs)	
4	40% Special Gelatin	42	25	141	138	73.14	Full face shot, 3 sticks did not detonate
		43	25	124	123	65.19	Full face shot, 1 stick did not detonate
		44	25	111	111	58.83	Full face shot
		45	25	108	108	57.24	" " "
		46	25	110	110	58.30	" " "
		47	25	111	111	58.83	" " "
		48	25	109	109	57.77	" " "
		49	25	109	109	57.77	" " "

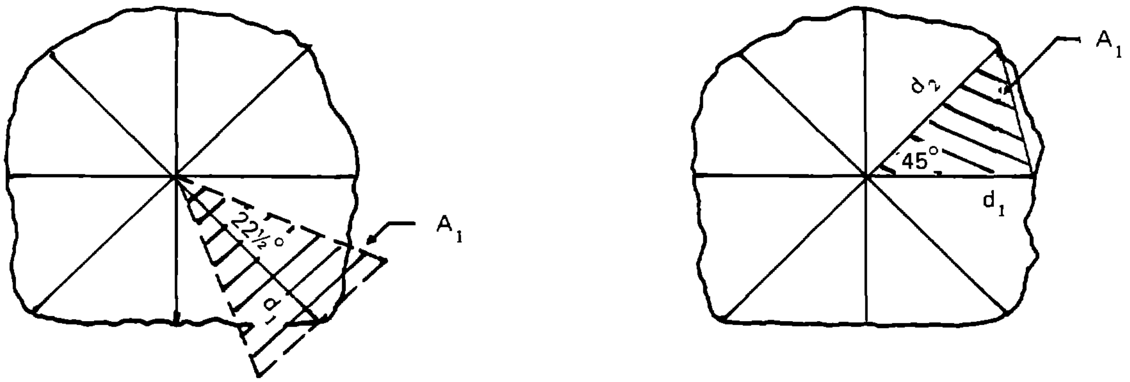
Table 4. Comparison of Containment Volume Determined by Physical Measurement and CO_2 Dilution

Experiment No.	Containment Volume (ft^3)		Difference (%)
	Physical Measurement	CO_2 Dilution	
28	9075	9181	1.0
35	10522	10734	2.0
41	12217	11688	4.0
49	14901	12853	14.0

A. Cross-section Area Determination

Method 1. Overestimates 5-10%

Method 2. Underestimates 5-10%



Area: $A_1 = d_1^2 \tan 22\frac{1}{2}^\circ$

Adit Cross-sectional Area:

$A_0 = A_1 + A_2 + \ldots + A_8$

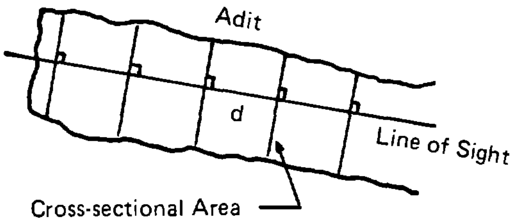
Area: $A_1 = \frac{1}{2} d_1 \cdot d_2 \sin 45^\circ$

Adit Cross-sectional Area:

$A_u = A_1 + A_2 + \ldots + A_8$

Average Cross-sectional Area = $\frac{1}{2}(A_0 + A_u)$

B. Adit Section Volume Determination



Section Volume: $V_s = A_i \, (d \cdot f)$

where: A_i = Area of ith Section

d = Depth of Section

f = Factor to correct for End Section

C. Containment Volume Determination

Containment Volume = Sum of the Volume of All Sections

Figure 7. Containment Volume Determination by Physical Measurement

Scaled Studies

The purpose for conducting scaled tests is to determine if the concentration of gases produced per unit mass of explosives detonated remains constant; ideally, this should occur. However, under actual mining conditions where variables such as moisture content of the air, completeness of detonation, production of dust, fractures in the rock mass and adsorption or absorption of the gas by the rock surfaces affect the amount of gas liberated, one can expect some degree of variability in the airbone concentration of gases from shot to shot.

Scaling tests were conducted on two explosives, Iremite 40 and Amogel No. 3. The amounts of explosive used for each of the nine tests per explosive appear in Table 3.

Instrumentation

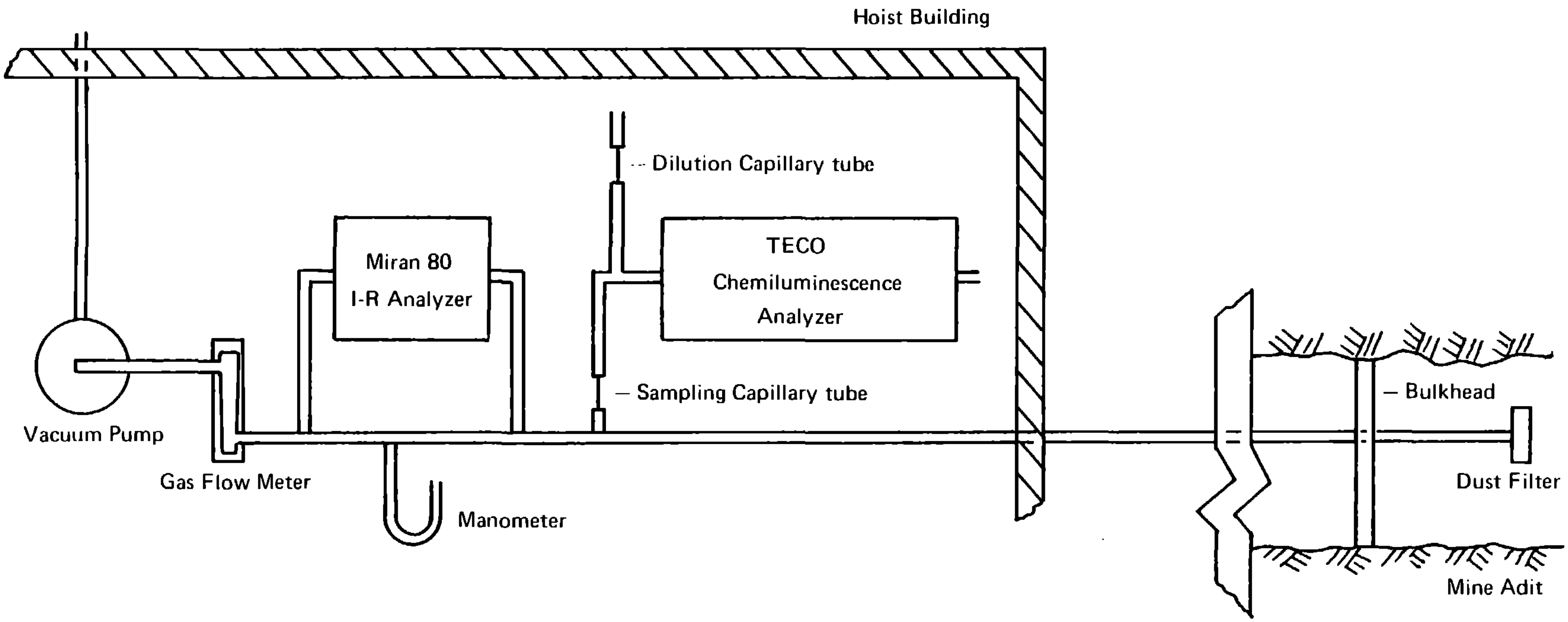
General Information

Lack of a suitable underground facility near the test chamber made it necessary to locate and operate the analytical equipment in the hoist building. This required drawing the air sample from the mine through 225 feet of 0.5 in diameter Teflon tube. The sampling manifold was constructed of glass, Teflon and stainless steel (Figure 8). The air sample was drawn continuously from the mine during the test period at a rate of 2.0 to 2.6 m^3/hr and analyzed by chemiluminescence and infrared analyzers (Table 5).

Chemiluminescence Analyzer

A Thermo Electron Corporation (TECO), Model 14B/E analyzer was used to monitor for oxides of nitrogen (considered to consist of nitric oxide and nitrogen dioxide only). To determine the concentration of each gas, discrete sample segments were alternately scanned by the instrument for 30 seconds. The first segment was evaluated for the presence of free nitric oxide where nitric oxide was measured by detection of the chemiluminescence created by the reaction between it and ozone. In the alternate 30 second segment, free NO_2 in the sample was reduced to NO by passing the gas stream through a molybdenum screen at 375°C; the total concentration of NO was then evaluated. By substracting the initial concentration of NO from the second or total value, the concentration of NO_2 was calculated.

In the "off the shelf" TECO analyzer, the air sample is drawn through a capillary orifice with a flowrate of approximately 750 ml/min. This results in an upper limit of detection for NO of 10 ppm. This limit was too low for the concentration of gases generated by detonation of explosives. By adjusting the "gain" on the instrument the upper limit was extended to 25 ppm, however, this was not enough. To increase the range of detection, a smaller orifice was installed to decrease the sample volume. This resulted in a higher upper limit of detection but rendered the operating mode of the instrument too sensitive to pressure variations in the sampling manifold. To overcome this problem, a dilution system had to be installed. The sample dilution system consisted of placing the original 750 ml/min orifice, (open to the atmosphere) in a tee-configuration with a smaller capillary orifice connected to the sampling line (Figure 8). This configuration allowed the



Not to Scale

Figure 8. Schematic Diagram of Sampling Manifold and Analytical Instruments

Table 5. Gas Analyzers and Their Detection Limits

	Analyzer Detection Limits	
Gas	Foxboro/Wilkes Miran-80	TECO, Model 14B/E
Carbon Monoxide	50 - 2000 ppm	NA
Carbon Dioxide	0 - 2%	NA
Ammonia	0 - 50 ppm	NA
Water Vapor @ 70-80°F	0 - 50% R.H.	NA
Sulfur Dioxide	0 - 50 ppm	NA
Nitric Oxide	10 - 200 ppm	0 - 10 ppm
Nitrogen Dioxide	10 - 200 ppm	0 - 10 ppm

NOTE: The Foxboro/Wilkes instrument was not approved for the measurement of the oxides of nitrogen.

instrument to draw 750 ml/min of room air and approximately 3.8 ml/min of sample thus overcoming the pressure variation problem and increasing the upper detection limit of the instrument to 5000 ppm.

Calibration of NO-NO_x Analyzer

The TECO, NO-NO_x analyzer was calibrated with two span gases in nitrogen (20 ppm NO_2 and 607 ppm NO, respectively). The gases were admitted into the air sampling line of the instrument, the line pressure was adjusted to simulate normal sampling conditions and the readings on the instrument were noted. The ratio of the known concentration value and that measured by the instrument was applied as the correction factor to the test data. This procedure was observed before each shot. Zero and sensitivity drift were found to be quite low over the course of the project; a fact confirmed by laboratory calibrations conducted at other concentration levels.

Infrared Analyzer

A Foxboro/Wilks, Miran-80 Infrared Analyzer was used to monitor for CO, CO_2, SO_2,and NH_3. This instrument is a new quantitative analytical system combining a single beam spectrometer with a programmable microcomputer system. The analyzer accepts multi-component gaseous samples and permits analysis of the individual components. In routine applications the controlling microprocessor is programmed to perform matrix algebra on the data; subtracting interferences due to each component at each infrared wavelength and producing a real-time printout of the concentration of the components.

Calibration of I-R Analyzer

The Miran-80 was calibrated in the laboratory using a sealed recirculating system constructed of glass and Teflon and equipped with a sample-injection system. To select the appropriate wavelength for each component, a sample of the gas in question, as a pure gas or as a mixture of gases, was injected into the calibration stream and the infrared spectrum, 2.0 to 14.5μm, was scanned. The choice of the wavelength used was based on considerations of adequate intensity and relative freedom from interference by other components. Wavelengths selected for each gaseous species are listed in Table 6.

Some feeling for the effect of interference produced by each gaseous component may be obtained by examination of Table 7. These values are based on the range of absorbances measured during the first explosive, Iremite 40, and represents the worst-case values. That is, estimates were made of the maximum amount of a given interfering gas and the minimum amount of the gas interfered with as seen during the Iremite 40 series. The absorbances at the wavelength of the gas interfered with were measured and the percent interference calculated. For example, the minimum estimated amount of CO_2 produced during this series gives an absorbance value of 0.3267 and the maximum estimated amount of CO present gives an absorbance value of 0.0025 at the CO_2 wavelength; thus, the worst-case interference of CO with CO_2 would be:

Table 6. Infrared Wavelengths for Monitored Species

Species	Wavelength (μm)
(reference)	3.670
CO_2	4.278 (shoulder)
CO	4.768
NO	5.518
NO_2	6.132
SO_2	7.231
NH_3	10.550
H_2O	6.758

Table 7. Mutual Interference Levels of Monitored Species

Monitored	Interference Level by Gas Species (%)						
Species	CO_2	CO	NO	NO_2	SO_2	NH_3	H_2O
CO_2	-	0.8	1.2	0.4	0	0	8.4
CO	2.1	-	0.9	2.6	0.1	0	30.0
NO	2.4	2.4	-	18.7	1.5	1.8	770
NO_2	0.1	1.0	3.7	-	0	2.5	38
SO_2	0.7	0	0.2	4.3	-	0	66
NH_3	4.8	0.7	0	1.8	2.1	-	26
H_2O	1.3	0.3	0	0.03	0.2	0.9	-

$$\text{Interference Level}(\%) = \frac{0.0025 \times 100}{0.3267} = 0.8$$

Note: This value is the maximum interference caused by the interfering gas.

Water vapor is the major source of interference for all gases and is particularly troublesome with nitric oxide.

A disproportionate amount of time and effort was spent attempting to operate the Miran-80 as promoted by the manufacturer. The basic problem was in constructing a matrix that would give acceptable values for gaseous compositions differing in relative proportion from those used to construct the calibration matrix. These difficulties led us to speculate that the problem was not in actual physical interferences, but in the dynamic range demanded of the matrices; the matrix program could not handle the wide range of absorbance values (e.g., readings as low as 0.0075 for NH_3 and 2.0 and higher for NO_2). This problem is illustrated in Table 8. As can be seen from this table, a great variation in values computed by the microprocessor is observed with each change of the NO_2 test concentration. To overcome this problem, the number of gases evaluated by a given matrix were reduced and the lower and upper concentration ranges for each gas were set. Table 9 shows the ranges selected for each gas; these are based on concentration levels observed while testing the Iremite 40 and Amogel No. 3 explosives. In order to develop matrices that would give acceptable values in these selected ranges, calibration mixtures spanning these ranges were made and the absorbance values for these mixtures were determined. However, instead of inserting values for all gases into the Miran-80 microcomputer program, only the values for the desired gases and possibly one or two of the more important interference gases were used. This approach produced satisfactory results, but sacrificed one of the main advantages of the Miran-80 instrument, automatic processing of the data. In other words, simultaneous real-time calculation of the gas concentrations could not be automatically performed because the Miran-80 was only able to handle one matrix at a time. Processing of the data now required loading a given matrix into the Miran-80 and input of arbitrary absorbance values. Since the Miran-80 utilizes only linear equations, output from the microcomputer provided information about the slope and intercepts implicit in each matrix. This information was used to derive equations that could be handled in a manual calculator. Table 10 shows the equations that were developed for each gas at specific absorbance levels.

Another problem with the Miran-80 which was detected after the scaling tests had been completed on the first explosive, Iremite 40, was the drifting of the value for the reference wavelength. The purpose for the reference wavelength is to act as a monitor of instrument drift or as an alert for interferences by particulates in the air sample; any absorbances appearing in the reference wavelength are automatically subtracted from the absorbances at all other wavelengths. The drift was erratic and unpredictable. At first, dust particles in the gas stream were suspected as the cause of the reference wavelength drift, but increased attention to the adequacy of the particulate filter at the sampling head did not produce any improvement; the problem was noted to occur even in laboratory calibration runs where dust was not a problem.

It was noticed while shakedown tests were being conducted in the laboratory to resolve the drift problem, that injection of water vapor alone

Table 8. Variation in Miran-80 Matrix Print-out of Computed Concentration of CO_2, NO_2 and SO_2 with Actual Concentration Caused by Injection of Varying Concentrations of NO_2 Into the Test Gas Stream

Actual Gas Concentration (ppm)		Computed Concentration of Gas Species With Varying Concentration of NO_2 (ppm)			
		NO_2 Injection (ppm)			
		175	260	350	400
CO_2	31600	39000	26000	19000	0
NO_2	-	170	360	460	1160
SO_2	23	50	70	80	180

Table 9. Operational Concentration Ranges for Each Gas Species by Matrix

Species	Range of Concentrations (ppm)	
	Matrix I	Matrix II
CO_2	7500 - 19000	31600 - 49100
CO	350 - 940	1750 - 4750
NO	120 - 300	140 - 220
NO_2	225 - 450	175 - 440
SO_2	0 - 65	23 - 62
NH_3	0 - 125	100 - 250
H_2O	13500 - 17700	15000 - 29000

Table 10. Equations For Calculation of Gas Concentrations by Matrix

Matrix I	Matrix II
$CO_2 = 4.81(A_{CO_2}) - 10440$	$CO_2 = (A_{CO_2}) + 0.7(A_{CO}) - 15200$
$CO = 0.738(A_{CO}) - 681$	$CO = 1.357(A_{CO}) - 0.07(A_{CO_2}) - 1780$
$SO_2 = 0.0202(A_{SO_2}) - 21.7$	$SO_2 = 0.0184(A_{SO_2}) + 0.0014(A_{H_2O}) - 25$
$NH_3 = 0.0945(A_{NH_3}) - 0.0009(A_{H_2O}) - 2.7$	$NH_3 = 0.1468(A_{NH_3}) - 52$

NOTE: "A" is the absorbance value on the instrument readout multiplied by 10,000 initiated the drift and became worse over a period of 5 - 15 minutes of operation. This suggested that repeated exposure of the optical components to moisture and highly reactive gases had caused some alteration of the component surfaces. It was decided to suppress the drift correction by forcing the reference absorbance value to zero. By manual programming of a large gain into the amplifier for the reference wavelength, 3.6μ m, the reference absorbance value of zero was maintained in spite of surface effects that might be occuring in the optical component. While the problem of apparent absorption by water vapor at 3.670μm is not completely understood, it has been determined that absorbance by water vapor is not a problem at the wavelengths used to measure the gases in the tests.

Test Operating Procedure

The following procedure was established to assure that the tests were conducted in a consistent manner:

1. The miners drill the holes.

2. Connect the recirculation fan to the ventilation duct inside the test chamber.

3. At least one hour before detonating the explosive, the analytical instruments are to be turned on and the necessary preparation and calibration of the instruments are to be performed.

4. While preparation of the instruments is being done, the temperature and relative humidity in the mine are to be recorded. Barometric pressure at the hoist house is also recorded.

5. Measure the drift for containment volume calculation.

6. Load the explosive and blast. The explosive is to be detonated within 24 hours after being loaded in the holes.

7. Close and secure the door at the bulkhead as soon as the last delay detonates.

8. Turn on the recirculation fan.

9. Start recording the gas sampling results displayed by the instruments. Record the data until the gas concentrations show a marked reduction due to decay.

10. Turn off recirculation fan, open the door at the bulkhead and ventilate the drift.

11. After the mine drift is sufficiently ventilated, inspect the work area, bar down and install roof bolts and wire mesh.

12. Remove the muck pile. Make a note of any undetonated explosives .

13. Prepare the drift for another test cycle.

EXPERIMENTAL RESULTS

Measurement of Gas Concentration

The concentration of each of the gases produced by detonation of the explosives was determined by two instruments selected for this study. $NO-NO_2$ values displayed on the meter of the TECO instrument were recorded manually every 30 seconds; alternating between NO and NO_2. These values were adjusted by the correction factor determined during calibration to calculate the concentration as parts per million. Values for CO, CO_2, SO_2, and NH_3 were automatically recorded every 50 seconds by the Miran-80 instrument. These values were then used in the appropriate equation to calculate the concentration of each gas as parts per million.

Tables 11 - 16 show the concentrations of the six gases present after each shot with each explosive; Table 11 and Table 12 show the results of the scaling tests and Tables 13 - 16 show the results of the full face shots. The concentration values listed were calculated from measured values and correspond to having the product gases perfectly mixed in the total sample volume immediately after the blast.

Computed Gas Volume

The computed gas volume per mass of explosive is defined as the volume of gas produced at ambient mine conditions by a given amount (mass) of explosive and is expressed as:

$$V_m = \frac{\text{Volume of gas}}{\text{mass of explosive}}$$

$$= \frac{\text{gas concentration (ppm) x containment volume (ft}^3\text{) x } 10^{-6}}{\text{mass of explosive (lbs)}}$$

where: V_m is the computed gas volume expressed in cubic feet per pound of explosive (ft^3/lb)

The volume of each gas produced after each shot for each explosive tested is shown in Tables 17 through 22. Gas volume expressed as l/kg and as $ft^3/200$ grams for each explosive is tabulated in Appendix A.

A summary of the arithmetic mean values for the computed volumes is presented in Table 23.

Table 11. Gas Concentrations During Scaling Tests With <u>IREMITE 40</u>, Water Gel Explosive

Experiment No.	Explosive Amount (lbs)	Containment Volume		Gas Concentration (ppm)					
		Physical Measurement (ft^3)	CO_2 Dilution (ft^3)	NO	NO_2	CO	SO_2[(b)]	NH_3	CO_2
2	2.40	4318		(a)	(a)	70.1	0.4	(c)	1250
3	3.19	4318		(a)	(a)	54.3	1.5	(c)	1170
5	3.19	4459		30.1	6.3	47.6	0.5	(c)	650
8	4.73	4495		42.9	6.8	62.2	1.9	(c)	2165
3a	4.80	4318		(a)	(a)	186.2	1.6	(c)	1120
4	4.80	4318		45.7	3.5	128.0	2.3	(c)	2240
6	7.19	4459		105.0	23.7	137.0	2.2	(c)	2910
7	7.99	4459		69.6	25.7	190.0	2.2	(c)	3750
1	9.57	4318		(a)	(a)	244.0	4.1	(c)	4600

(a) Analyzer not yet in place

(b) Values projected by using CO_2 loss rate from the same run

(c) All values were less than 6 ppm

Table 12. Gas Concentrations During Scaling Tests With AMOGEL NO. 3, Semigelatin Dynamite

Experiment No.	Explosive Amount (lbs)	Containment Volume[(a)]		Gas Concentration (ppm)					
		Physical Measurement (ft^3)	CO_2 Dilution (ft^3)	NO	NO_2	CO	SO_2	NH_3	CO_2
24	3.34		8222	107	29.0	340	7.5	20.3	1950
22	4.62		7552	157	65.5	268	7.8	21.3	2490
18	5.04		6669	(b)	(b)	250	6.7	16.3	2850
19	5.04		6881	122	44.7	212	4.8	10.1	2730
20	5.04		7093	169	68.8	325	1.3	10.1	3450
21	5.04		7340	117	27.3	264	8.3	11.0	2640
17	10.05		6211	(b)	(b)	459	9.0	34.5	5970
25	10.05		8681	211(d)	119(d)	(e)	(e)	(e)	(e)
23	12.56		7904	(c)	(c)	525	15.9	43.3	5140

(a) Interpolated where necessary

(b) Analyzer manifold not yet in place

(c) Analyzer manifold failure

(d) Estimated concentration

(e) Infrared analyzer failure

Table 13. Gas Concentrations During Full Face Shots With <u>IREMITE 40</u>, Water Gel Explosive

Experiment No.	Explosive Amount (lbs)	Containment Volume$^{(a)}$		Gas Concentration (ppm)					
		Physical Measurement (ft^3)	CO_2 Dilution (ft^3)	NO	NO_2	$CO^{(c)}$	$SO_2{}^{(c)}$	$NH_3{}^{(c)}$	$CO_2{}^{(c)}$
9	52.93		4383	(b)	(b)	720	8.8	34	16040
10	52.93		4590	(b)	(b)	1100	16.0	36	21620
11	50.96		4802	(b)	(b)	560	10.2	26	13290
12	52.93		5049	(b)	(b)	550	6.7	24	11060
13	52.93		5296	(b)	(b)	510	7.0	23	11560
14	52.93		5508	(b)	(b)	570	8.2	26	15410
15	52.93		5755	(b)	(b)	680	15.5	30	16580
16	52.93		5967	(b)	(b)	720	14.1	29	14220

(a) Interpolated where necessary

(b) Oxides of nitrogen not measured due to limited detection range of TECO Analyzer

(c) Values estimated using graphic projection method for each test

Table 14. Gas Concentrations During Full Face Shots With AMOGEL No. 3, Semigelatin Dynamite

Experiment No.	Explosive Amount (lbs)	Containment Volume[a]		Gas Concentration (ppm)					
		Physical Measurement (ft^3)	CO_2 Dilution (ft^3)	NO[b]	NO_2[b]	CO[c]	SO_2[c]	NH_3[c]	CO_2[c]
26	59.22	8686		380	380	2840	35.3	154	45220
27	60.48	8898		500	420	2330	32.1	146	36950
28	57.96	9075	9181	550	750	2570	32.0	164	38340
29	59.22	9787		420	490	(d)	(d)	(d)	(d)
30	58.38	9498		430	620	2580	39.9	163	40090
31	56.70	9675		390	630	2060	22.1	115	36950
32	59.64	9887		(e)	(e)	(e)	(e)	(e)	(e)
41[f]	55.44	12217	11688	140	200	1060	25.0	61	12780

(a) Interpolated where necessary

(b) Values estimated by: $\frac{CO_{2(t)} \times NO_{x(t)}}{CO_{2(t)}}$ (see text)

(c) Values estimated using graphic projection method for each Test (see text)

(d) Values too erratic; values did not peak nor reach equilibrium

(e) Mixing fan in test drift failed

(f) This test was conducted out of sequence

Table 15. Gas Concentration During Full Face Shots With DYNAGEL 205, Water Gel Explosive

Experiment No.	Explosive Amount (lbs)	Containment Volume[a]		Gas Concentration (ppm)					
		Physical Measurement (ft^3)	CO_2 Dilution (ft^3)	NO[b]	NO_2[b]	CO[c]	SO_2[c]	NH_3[c]	CO_2[c]
33	55.46	10134		186	100	710	15.7	38	14460
34	59.00	10275		170	140	740	14.8	37	19380
35	60.18	10522	10734	170	100	580	13.4	33	16250
36	54.87	10770		170	120	470	12.0	29	12060
37	54.28	10981		(d)	(d)	(d)	(d)	(d)	(d)
38	57.82	11229		160	120	620	16.5	41	9260
39	54.87	11546		170	130	400	11.6	23	9840
40	58.41	11899		120	90	570[e]	13.5[e]	30[e]	11030[e]

(a) Interpolated where necessary

(b) Values estimated by: $\frac{CO_{2(p)} \times NO_{x(t)}}{CO_{2(t)}}$ (see text)

(c) Values estimated using graphic projectiion method for each test (see text) unless otherwise noted

(d) Mixing fan in test drift not operating

(e) Values estimated using average leak rates

Table 16. Gas Concentrations During Full Face Shots With <u>40% SPECIAL GELATIN</u>, Gelatin Dynamite

Experiment No.	Explosive Amount (lbs)	Containment Volume[(a)]		Gas Concentration (ppm)					
		Physical Measurement (ft^3)	CO_2 Dilution (ft^3)	NO[(b)]	NO_2[(b)]	CO[(c)]	SO_2[(c)]	NH_3[(c)]	CO_2[(c)]
42	73.14	12570		400	160	1020	15.4	41[(d)]	11950
43	65.19	12888		510	170	980	15.8	52[(d)]	10170
44	58.83	13206		540	130	760	9.9	27	7950
45	57.24	13559		480	200	910	14.7	46	10590
46	58.30	13877		570	110	780	16.2	53[(d)]	7090
47	58.83	14230		450	140	870	16.8	47	6610
48	57.77	14548		570	120	670	14.0	37[(d)]	4540
49	57.77	14901	12853	420	110	790	13.9	39[(d)]	5890

(a) Interpolated where necessary

(b) Values estimated by: $\frac{CO_{2(p)} \times NO_{x(t)}}{CO_{2(t)}}$ (see text)

(c) Values estimated using graphic projection method for each test (see text) unless otherwise noted

(d) Values estimated using average leak rates (see text)

Table 17. Computed Gas Volume Produced During Scaling Tests With IREMITE 40, Water Gel Explosive

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume (ft^3/lb)					
			NO	NO_2	CO	SO_2 (b)	NH_3	CO_2
2	2.40	4318	(a)	(a)	0.126	0.001	(c)	2.25
3	3.19	4318	(a)	(a)	0.073	0.002	(c)	1.58
5	3.19	4459	0.042	0.009	0.066	0.001	(c)	0.90
8	4.73	4495	0.040	0.006	0.058	0.002	(c)	2.02
3a	4.80	4318	(a)	(a)	0.078	0.001	(c)	1.01
4	4.80	4318	0.041	0.003	0.115	0.002	(c)	2.02
6	7.19	4459	0.065	0.015	0.085	0.001	(c)	1.80
7	7.99	4459	0.039	0.014	0.106	0.001	(c)	2.09
1	9.57	4318	(a)	(a)	0.110	0.002	(c)	2.07
		Mean	0.040 (d)	0.010	0.091	0.001	(c)	1.75
		Standard Deviation	0.001	0.004	0.023	0.001	(c)	0.46

(a) Analyzer not yet in place
(b) Values projected by using CO_2 loss rate from the same run
(c) Not calculated, levels are too low
(d) The value from Experiment No. 6 not included in calculation of the mean value

Table 18. Computed Gas Volume Produced During Scaling Tests With AMOGEL NO. 3, Semigelatin Dynamite

Experiment No.	Explosive Amount (lbs)	Containment[(a)] Volume (ft^3)	Gas Volume (ft^3/lb)					
			NO	NO_2	CO	SO_2	NH_3	CO_2
24	3.34	8222	0.26	0.07	0.83	0.018	0.050	4.78
22	4.62	7552	0.26	0.11	0.44	0.013	0.035	4.07
18	5.04	6669	(b)	(b)	0.34	0.009	0.022	3.79
19	5.04	6881	0.17	0.06	0.29	0.007	0.014	3.74
20	5.04	7093	0.25	0.10	0.46	0.010	0.026	4.86
21	5.04	7340	0.16	0.04	0.38	0.012	0.023	3.85
17	10.05	6211	(b)	(b)	0.28	0.006	0.021	3.69
25	10.05	8681	0.18	0.10	(d)	(d)	(d)	(d)
23	12.56	7904	(c)	(c)	0.34	0.010	0.029	3.30
		Mean	0.21	0.08	0.36[(e)]	0.011	0.027	4.01
		Standard Deviation	0.04	0.02	0.06	0.004	0.010	0.51

(a) Interpolated where necessary
(b) Analyzer manifold not yet in place
(c) Analyzer manifold failure
(d) Infrared Analyzer failure
(e) Value from Experiment No. 24 not included in the calculation of the mean value

Table 19. Calculated Gas Volume Produced During Full Face Shots With IREMITE 40, Water Gel Explosive

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume (ft^3/lb) NO	NO_2	CO	SO_2	NH_3	CO_2
9	52.93	4343	(a)	(a)	.07	.001	.003	1.64
10	52.93	4590	(a)	(a)	.12	.002	.004	2.32
11	50.96	4802	(a)	(a)	.07	.001	.003	1.56
12	52.93	5049	(a)	(a)	.07	.001	.003	1.31
13	52.93	5296	(a)	(a)	.06	.001	.003	1.44
14	52.93	5508	(a)	(a)	.07	.001	.003	2.00
15	52.93	5755	(a)	(a)	.09	.002	.004	2.25
16	52.93	5967	(a)	(a)	.10	.002	.004	2.00
		Mean	(a)	(a)	.08	.001	.003	1.82
		Standard Deviation	(a)	(a)	.02	.001	.001	0.38

(a) Oxides of nitrogen not measured due to limited detection range of TECO Analyzer

Table 20. Calculated Gas Volume Produced During Full Face Shots With <u>AMOGEL No. 3</u>, Semigelatin Dynamite

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume (ft^3/lb)					
			NO	NO_2	CO	SO_2	NH_3	CO_2
26	59.22	8686	.07	.07	.52	.006	.03	8.28
27	60.48	8898	.09	.08	.43	.006	0.03	6.70
28	57.96	9075	.11	.15	.50	.006	.03	7.50
29	59.22	9287	.08	.10	(a)	(a)	(a)	(a)
30	58.38	9498	.09	.13	.52	.008	.03	8.16
31	56.70	9675	.08	.13	.44	.005	.02	7.90
32	59.64	9887	(b)	(b)	(b)	(b)	(b)	(b)
41	55.44	12217	.04	.06	.29	.007	.02	3.52
		Mean	.08	.10	.45	.006	.027	7.02
		Standard Deviation	.02	.03	.09	.001	.005	1.80

(a) Values too erratic; values did not peak nor reach equilibrium

(b) Mixing fan in test drift failed

Table 21. Calculated Gas Volume Produced During Full Face Shots With DYNAGEL 205, Water Gel Explosive

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume (ft^3/lb)					
			NO	NO_2	CO	SO_2	NH_3	CO_2
33	55.46	10134	.04	.02	.16	.004	.009	3.30
34	59.00	10275	.04	.03	.16	.003	.008	4.22
35	60.18	10522	.04	.02	.13	.003	.003	3.56
36	54.87	10770	.04	.03	.12	.003	.007	2.96
37	54.87	10981	(a)	(a)	(a)	(a)	(a)	(a)
38	57.82	11229	.04	.03	.15	.004	.010	2.26
39	54.87	11546	.04	.03	.10	.003	.006	2.58
40	58.41	11899	.03	.02	.14	.003	.008	2.82
		Mean	.04	.03	.14	.003	.008	3.10
		Standard Deviation	.004	0.01	0.02	.001	.001	0.66

(a) Mixing fan in test drift not operating

Table 22. Calculated Gas Volume Produced During Full Face Shots with 40% SPECIAL GELATIN, Gelatin Dynamite

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume (ft^3/lb)					
			NO	NO_2	CO	SO_2	NH_3	CO_2
42	73.14	12570	.09	.03	.22	.003	.009	2.56
43	65.19	12888	.13	.04	.24	.004	.013	2.50
44	58.83	13206	.15	.04	.21	.003	.008	2.22
45	57.24	13559	.14	.06	.27	.004	.014	3.12
46	58.30	13877	.17	.03	.23	.005	.016	2.10
47	58.83	14230	.14	.04	.26	.005	.014	2.00
48	57.77	14548	.18	.04	.21	.004	.012	1.42
49	57.77	14901	.14	.04	.25	.004	.013	1.88
		Mean	.14	.04	.24	.004	.012	2.22
		Standard Deviation	.03	.01	.02	.001	.002	.51

Table 23. Summary of Mean Values for Computed Gas Volume Produced During Full Face Shots With Each Explosive

Explosive	Average Gas Volume (ft^3/lb)					
Designation	NO	NO_2	CO	SO_2	NH_3	CO_2
IREMITE 40	(a)	(a)	.08	.001	.003	1.82
AMOGEL NO. 3	.08	.10	.45	.006	.027	7.02
DYNAGEL 205	.04	.03	.14	.003	.008	3.10
40% SPECIAL GELATIN	.14	.04	.24	.004	.012	2.22

(a) Not determined; limited detection range of analyzer

Comments

Three basic types of explosives were tested in this study:

1. A semigelatin dynamite, Apache Powder Co., Amogel No. 3.
2. A gelatin dynamite, Apache Powder Co., 40% Special Gelatin
3. Two metallized water gel explosives, Apache Powder Co., Dynagel 205 and Ireco, Iremite 40.

The explosives were tested in the following order: Iremite 40, Amogel No. 3, Dynagel 205 and 40% Special Gelatin. Scaling tests were conducted with Iremite 40 and Amogel No. 3.

As testing of the explosives progressed, it became evident that: a) mixing of the gases occurred in a damped-sinusoid pattern as the test chamber increased in volume and b) the concentration of the oxides of nitrogen decayed more rapidly than that of carbon dioxide, carbon monoxide or sulfur dioxide. These effects are shown in Figure 9 and Figure 10; the former representing a measurement made during an early test when the containment volume was relatively small and the latter representing a test when the containment volume was much greater.

To investigate the decay effect, the analysis period was extended in two tests to 60 and 100 minutes, respectively. By extending the sampling time the sinusoid effect was eliminated. Suspected loss of the gases due to reaction with or absorption by rock and equipment surfaces as well as by leakage appeared to be confirmed by this procedure. These losses were taken into account when calculating the concentrations reported. Correcting for these losses was accomplished in the following ways:

A. Determination of Initial CO, CO_2, SO_2 and NH_3 Concentrations

Semilog paper was used to plot gas concentrations of CO, CO_2, SO_2 and NH_3 versus time for the longer runs (and a number of the shorter runs). These gave a good straight line relationship which implied that the losses were dependent only on the concentration of the gas in the following manner:

$$-\frac{dC}{dt} = kC$$

By integrating, this loss equation becomes

$$C_t = C_o e^{-kt} \text{ or, } C_t = C_o \times 10^{-k't}$$

where: C_o is the initial concentration

C_t is the concentration at time, t, and

$k' = k \log_{10} e$

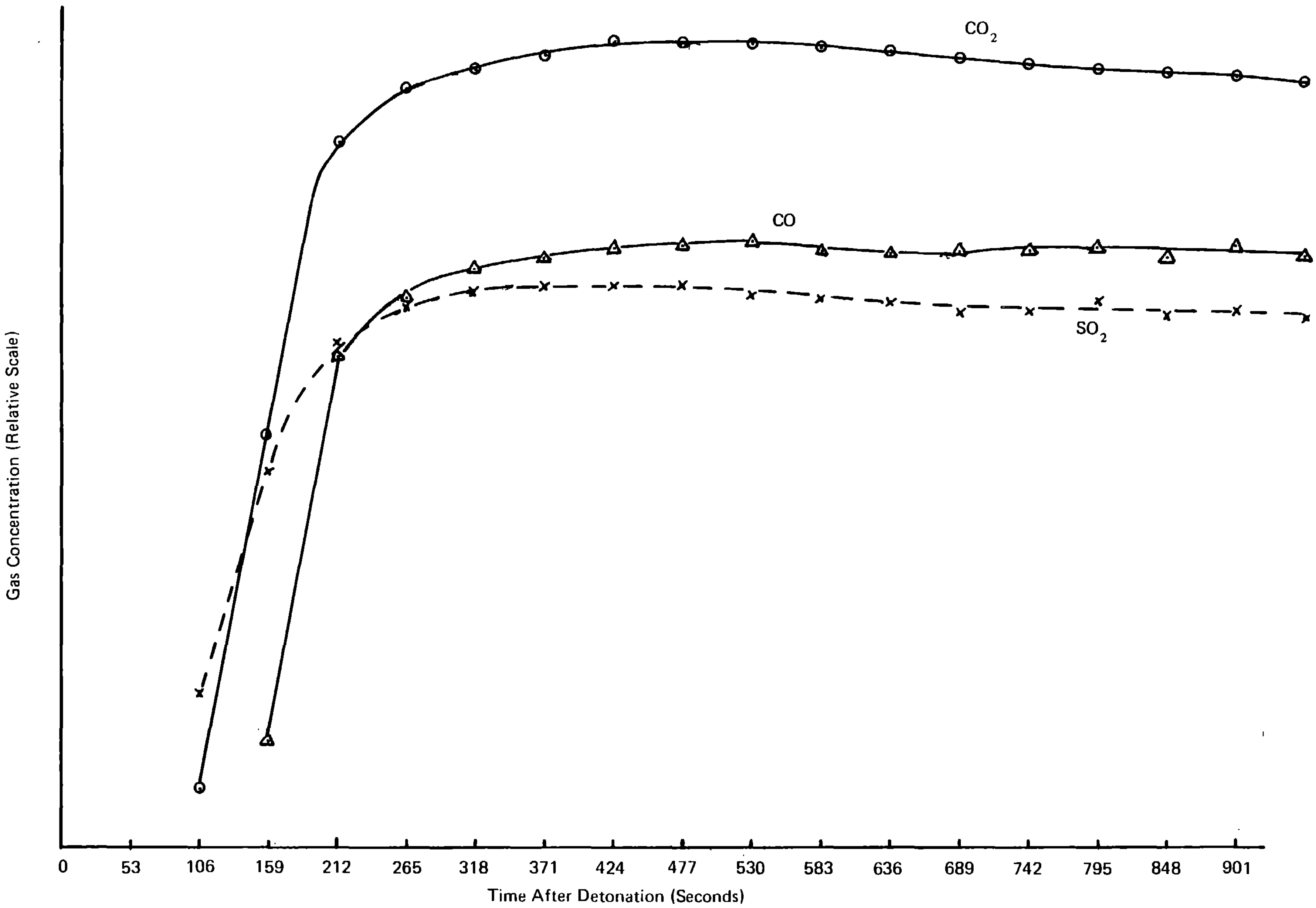


Figure 9. Relative Concentration Levels of CO, CO$_2$, and SO$_2$ During Shot No. 11 Versus Time After Detonation

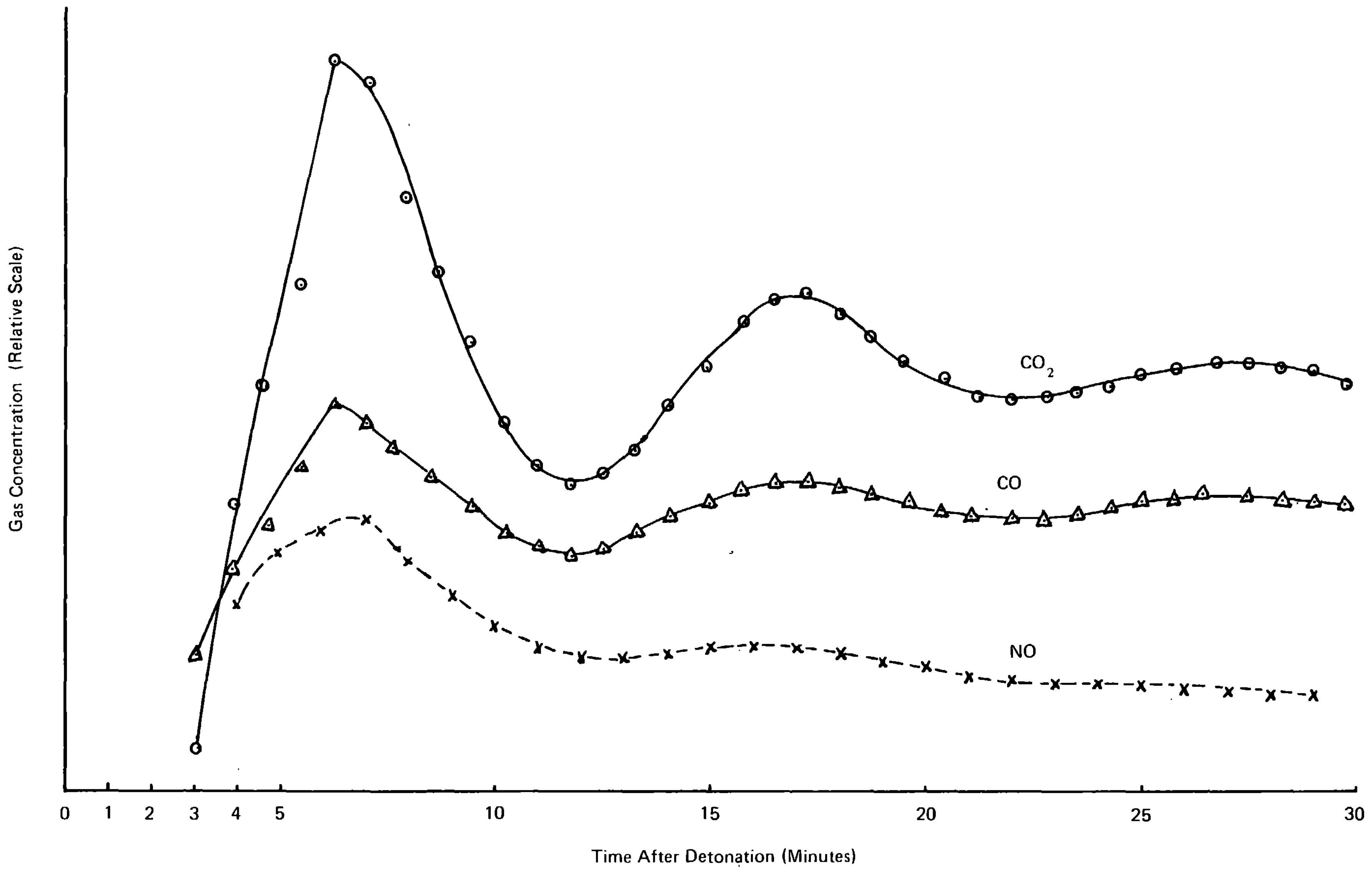


Figure 10. Relative Concentration Levels of CO, CO$_2$, and NO During Shot No. 49 Versus Time After Detonation

Losses of this nature ("first order") would be expected if the losses were due to leakage or absorption.

To apply this insight to data correction, a quiet portion of the field data for each run, usually the last 8 to 14 points where the sinusoid effect was absent, were graphed on semilog paper. A straight line was drawn and the slope determined by:

$$k' = \frac{\log C_2 - \log C_1}{t_2 - t_1}$$

where: C_2 is the value on the line coresponding to time, t_2 and
C_1 is the value on the line corresponding to time, t_1.

The value of k', loss constant calculated for each gas in each test, was used in the loss equation $C_t = C_o \times 10^{-k't}$ to calculate the initial concentration. This is not the concentration in the gas and dust cloud formed by the explosion, rather it represents the concentration in the test chamber if the gases mixed perfectly and instantaneously. With the exception of experiment Nos. 41, 42, 43, 46, 48 and 49, all values presented for CO, CO_2 SO_2 and NH_3 were calculated by applying this dilution equation.

Two checks on the validity of this technique were made:

1. In some of the earlier experiments where mixing was rapid and oscillation of the gas and dust cloud was minor, use of the loss equation was not so necessary since a reasonable estimate of C_o could be made by simple linear extrapolation of the graph of concentration versus time to time, t_o. However, as a check on the use of the loss technique, values for the initial concentration of CO_2 obtained by linear extrapolation were compared with values obtained using the loss equation for Experiment Nos. 9 through 16. The average difference in these values was ± 2% and the greatest difference was 7%. These uncertainties are considered to be less than the uncertainties associated with the instrument values and containment volume determinations.

2. To check on the validity of projecting initial gas concentrations using only a few points selected from a full run (typically the last 8-14 points), the entire results of several rounds (experiment nos. 10, 14, 27, 31, 44 and 45) were plotted on semilog paper and the initial concentrations, C_o's, estimated. The initial concentrations obtained by this method were compared to those calculated by the loss technique; results were satisfactory (Table 24).

Table 24. Initial Concentrations (C_o's) Estimated by Full-Run and Selected-Point Techniques

Experiment No.	CO_2			CO			SO_2		
	$C_{o(f)}$	$C_{o(s)}$	$\frac{C_{o(f)}}{C_{o(s)}}$	$C_{o(f)}$	$C_{o(s)}$	$\frac{C_{o(f)}}{C_{o(s)}}$	$C_{o(f)}$	$C_{o(s)}$	$\frac{C_{o(f)}}{C_{o(s)}}$
10	20740	21620	1.04	1070	1100	1.03	16.0	16.0	1.00
14	15940	15410	0.97	552	568	1.03	8.3	8.2	0.99
27	35930	36590	1.02	2170	2330	1.07	31.9	32.1	1.01
31	37710	36950	0.98	2330	2060	0.88	25.3	22.1	0.87
44	11020	7950	0.72	827	760	0.92	13.1	9.9	0.76
45	11860	10590	0.89	978	908	0.93			

NOTE: 1. $C_{o(f)}$ is the initial concentration estimated from the graph of the entire run

2. $C_{o(s)}$ is the initial concentration calculated from selected points by the loss equation

In six of the 32 experiments, the loss equation technique could not be applied to calculate the initial concentration. This was because oscillations of the gas front in Experiment Nos. 40, 42, 43, 46, 48 and 49 did not subside during the test periods. For these tests, a loss factor, "k" was developed that could be used in the loss equation. This factor was derived by averaging the loss or loss factor for each gas in the other 26 tests. After the average loss factor was obtained, the concentration value at time, t = 25 minutes, was used in the dilution equation to calculate the initial concentration which is reported in this study.

As a check on the reliability of this procedure, comparisons were made for each of the other 26 tests by calculating the loss at 25 minutes based on the specific loss factor for that test and by calculating the loss at the same time using the average loss factor. The values compared well; having an average error of ± 6% for CO, CO_2 and SO_2.

Rates of loss for each gas in various tests were compared to each other by calculating the fraction of gas remaining after 25 minutes (F_{25}) based on the observed loss equations. For example, if k' = 0.0000252/sec, then

$$F_{25} = \frac{C_{25}}{C_o} = \exp_{10}\ [-(.0000252/\text{sec}) \times 60\ \text{sec/min} \times 25\ \text{min}]$$

$$= 0.92$$

F_{25} varied from test to test; it ranged from 0.75 to 1.0.

The random scatter in the rate of loss suggests that variable factors such as closing the door of the containment, wall porosity and amount of rock fractures present, ambient moisture content, and the amount and nature of the dust have an impact on the rate. In general, the average rates of loss for individual gases were reasonably consistent: for CO, $F_{25} = 0.90 \pm 0.06$; for CO_2, $F_{25} = 0.87 \pm 0.06$; for SO_2, $F_{25} = 0.92 \pm 0.06$; and for NH_3, $F_{25} = 0.83 \pm 0.1$.

Based on these values, one can draw the following conclusion about the decay rates for these gases: NH_3 has the fastest decay rate.

B. Determination of Initial NO and NO_2 Concentrations

Preliminary observations and graphic presentations of the concentration of each gas vs time showed that the oxides of nitrogen decayed more rapidly and in a more complex fashion. Some time was spent trying to model these effects mathematically as had been done with the other four gases, but the results were not satisfactory.

A practical method of calculating the initial concentration of NO or NO_2 was obtained by taking the ratio of the calculated initial concentration of CO_2 to the concentration of CO_2 at the first peak (usually occuring 5 to 9 minutes after the blast) and multiplying by the observed concentration of NO or NO_2 at the same time, thus:

$$NO_{(initial)} = \frac{CO_{2(P)}}{CO_{2(t)}} \times NO_{(t)}$$

where: $NO_{(initial)}$ represents the initial concentration of NO

$CO_{2(p)}$ is the calculated initial concentration

$CO_{2(t)}$ is the observed concentration at a specific time on the first peak

$NO_{(t)}$ is the observed concentration of NO at the same time as $CO_{2(t)}$.

and

$$NO_2\ (initial) = \frac{CO_{2(P)}}{CO_{2(t)}} \times NO_2(t)$$

where: $NO_{2(initial)}$ represents the initial concentration of NO_2

$CO_{2(p)}$ is the calculated initial concentration

$CO_{2(t)}$ is the observed concentration at a specific time on the first peak

$NO_{2(t)}$ is the observed concentration of NO_2 at the same time as $CO_{2(t)}$

This approach made it possible to use the data obtained early in each test to minimize the effect of the rapid decay rate for the oxides of nitrogen.

DISCUSSION OF RESULTS

Scaled Tests

Scaled tests were conducted to determine if the volume of gas produced per unit mass of explosive remained constant regardless of the amount of explosive used in each shot. Figures 11 and 12 depict the results obtained on scaling tests for Iremite 40, a water gel explosive, and Amogel No. 3, a semigelatin dynamite. Each data point on the graphs represents a detonation. Only NO, NO_2, CO and CO_2 were plotted because their volume was high enough to be readily measured by the instrumentation.

With the exception of CO and CO_2 produced by Amogel No. 3, there appears to be little correlation between the computed gas volume per unit mass of explosive and the amount of explosive detonated in these scaling tests. Where correlation is apparent, the trend is toward a slight decrease in the computed volume with an increase in the amount of explosive used.

Full Face Tests

Figures 13 through 18 show the computed average volume of the six gases produced by the explosives during full face shots. From these bar graphs, it is apparent that the dynamite explosives, in general, produce more of each gas than the non-nitroglycerin explosives. Amogel No. 3, a semigelatin dynamite, produces the highest concentration of each gas, with the exception of NO_x; that is, it produces the greatest volume of toxic gases. In general, 40% Special Gelatin, a gelatin dynamite, follows Amogel No. 3 in production of gases. Unfortunately, owing to instrument problems experienced when Iremite 40 was being tested, the concentration of the oxides of nitrogen was not determined for this explosive. However, based on the volume of the other gases produced by Iremite 40 when compared to the other explosives, one is tempted to conclude that NO and NO_2 were also produced in the lowest concentration. With this assumption, Iremite 40, a water-gel explosive, produced the lowest volume of each gas. While Iremite 40 and Dynagel 205 are both water gel explosives, Iremite 40 produced significantly lesser amounts of CO, SO_2 and NH_3 than Dynagel 205.

Conclusions

Based on the results of this study, one can conclude that:

1. The volume of gases produced by the explosives during full face shots ranged widely:

NO:	0.03 - 0.18	ft^3/lb
NO_2:	0.02 - 0.15	" "
CO:	0.06 - 0.52	" "

SO_2: 0.001 - 0.008 ft^3/lb
NH_3: 0.003 - 0.03 " "
CO_2: 1.42 - 8.16 " "

2. In general, nitroglycerin based explosives (dynamites) produced a greater volume of each gas than non-nitroglycerin explosives.

3. Amogel No. 3 produced the highest volume of gases of the four explosives tested.

4. Iremite 40 produced the lowest volume of gases of the four explosives tested.

5. The concentration of the gases within the containment chamber decreased with time. The decay was more rapid for NO and NO_2. It is speculated that the decay could have been due to the reaction of the gases with each other and with surfaces of the mine wall and metallic equipment in the chamber. In addition some adsorption and/or absorption of the gases on the mine wall surfaces and dust particles as well as minor leakage through the bulkhead may have contributed to this loss.

6. Based on the results of the scaling tests, it was not possible to determine the effect of explosive mass on the volume of gases produced.

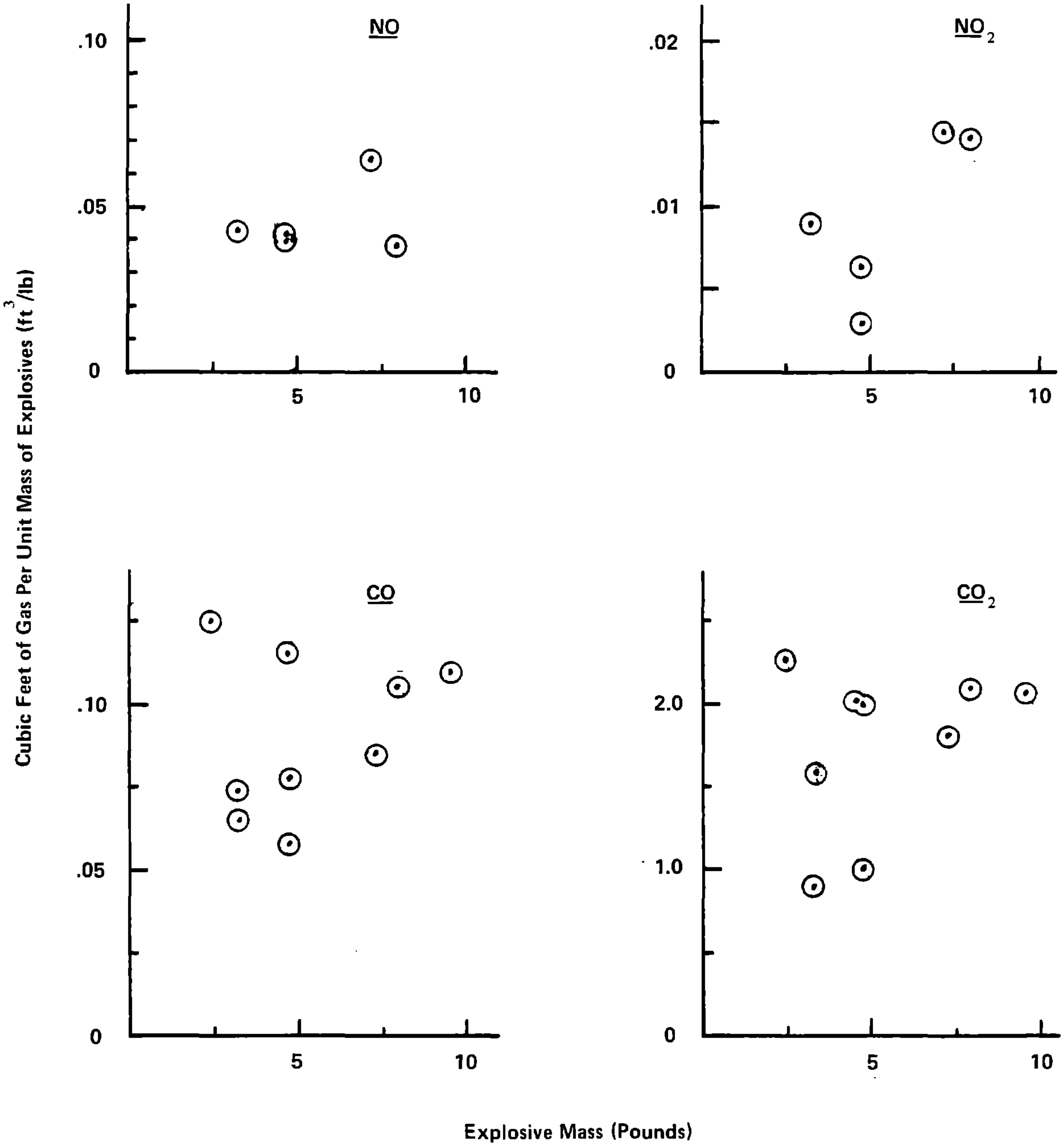


Figure 11. Computed Gas Volume Per Unit Mass of Explosive Versus Amount of IREMITE 40 Detonated During Scaled Tests

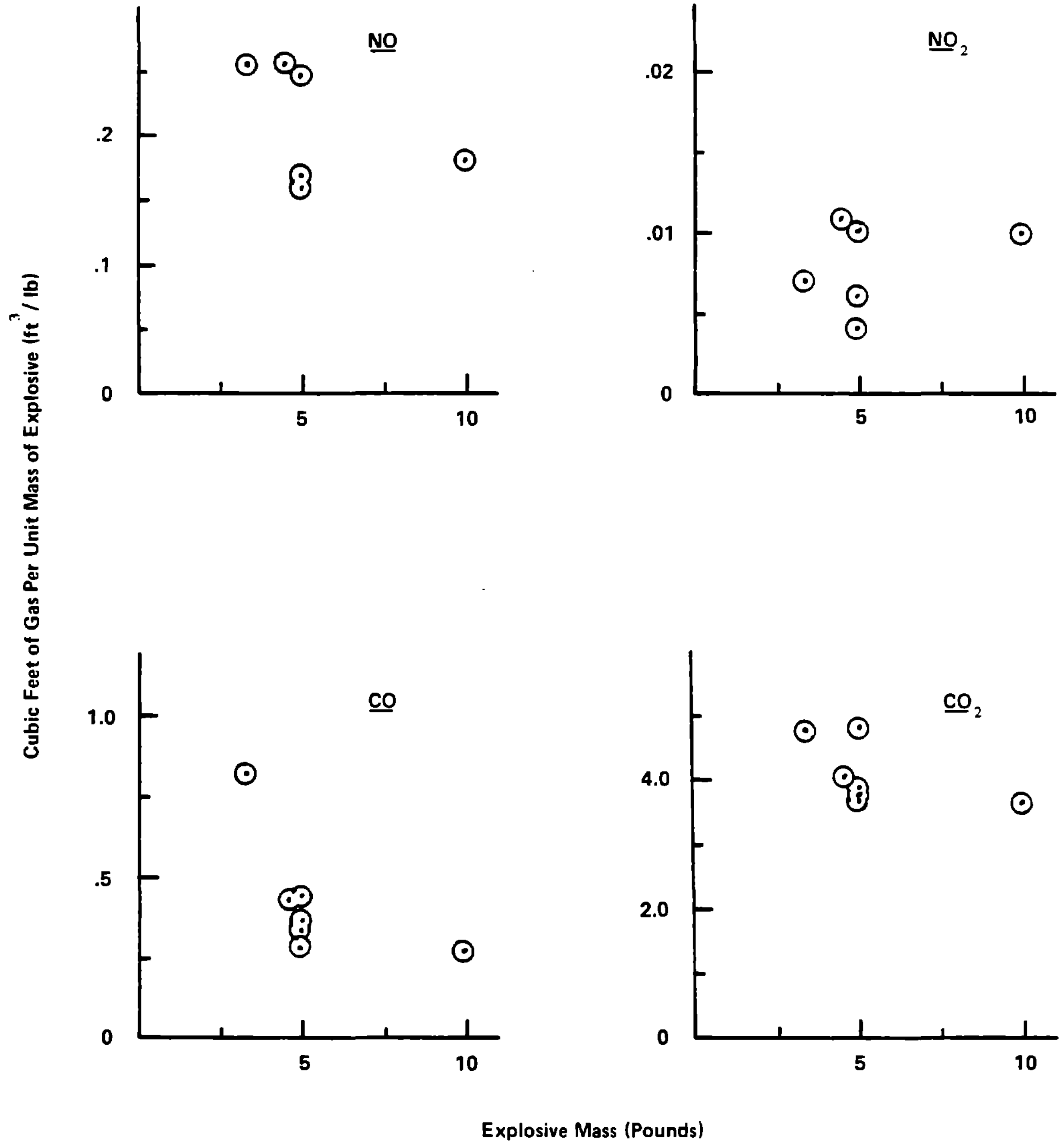


Figure 12. Computed Gas Volume Per Unit Mass of Explosive Versus Amount of AMOGEL NO. 3 Detonated During Scaled Tests

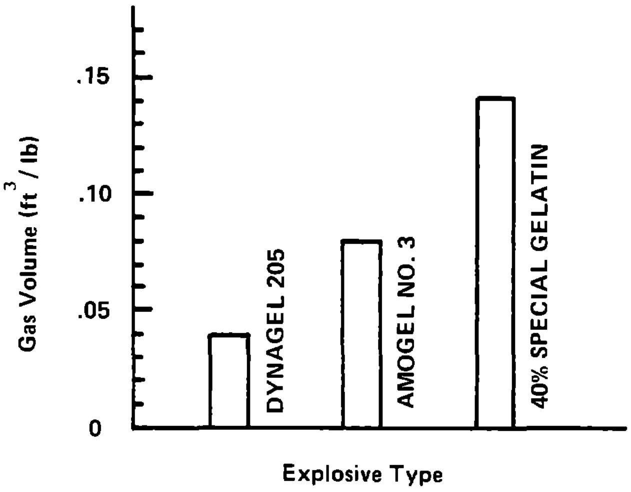


Figure 13. Average Volume of Nitric Oxide Produced by Each Explosive

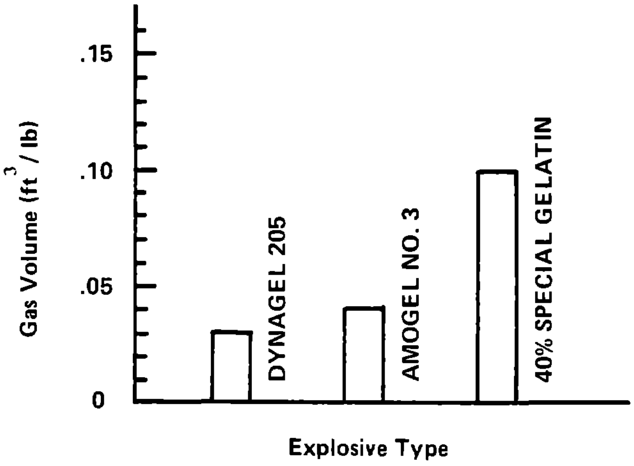


Figure 14. Average Volume of Nitrogen Dioxide Produced by Each Explosive

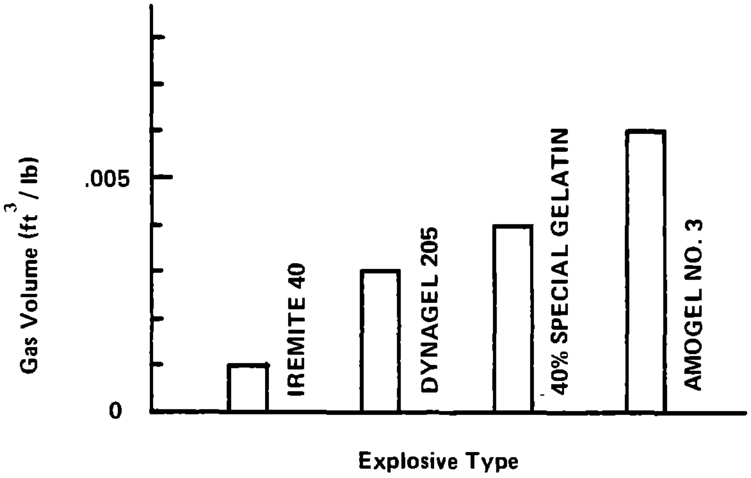


Figure 15. Average Volume of Sulfur Dioxide Produced by Each Explosive

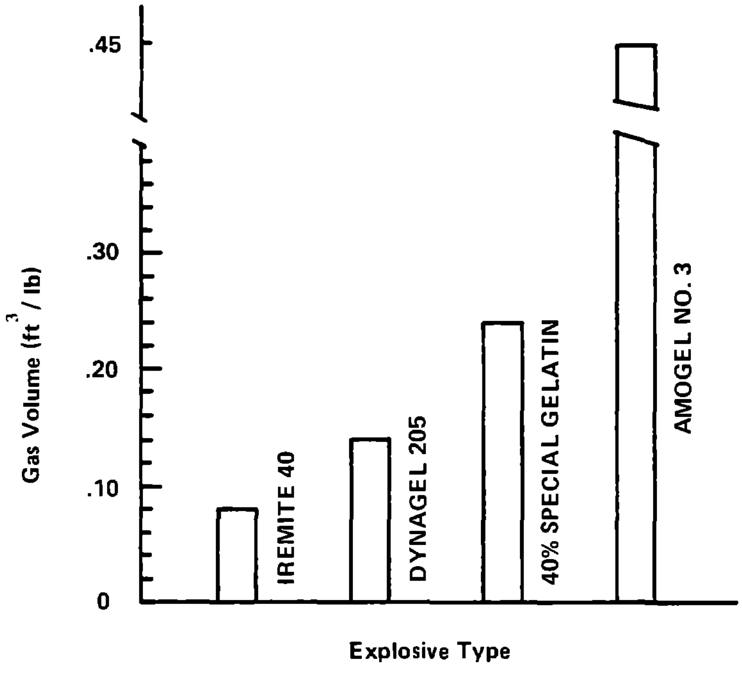


Figure 16. Average Volume of Carbon Monoxide Produced by Each Explosive

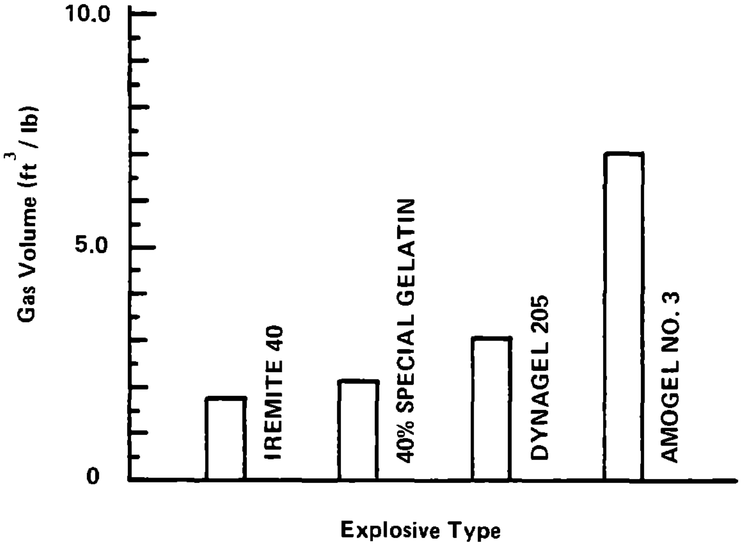


Figure 17. Average Volume of Carbon Dioxide Produced by Each Explosive

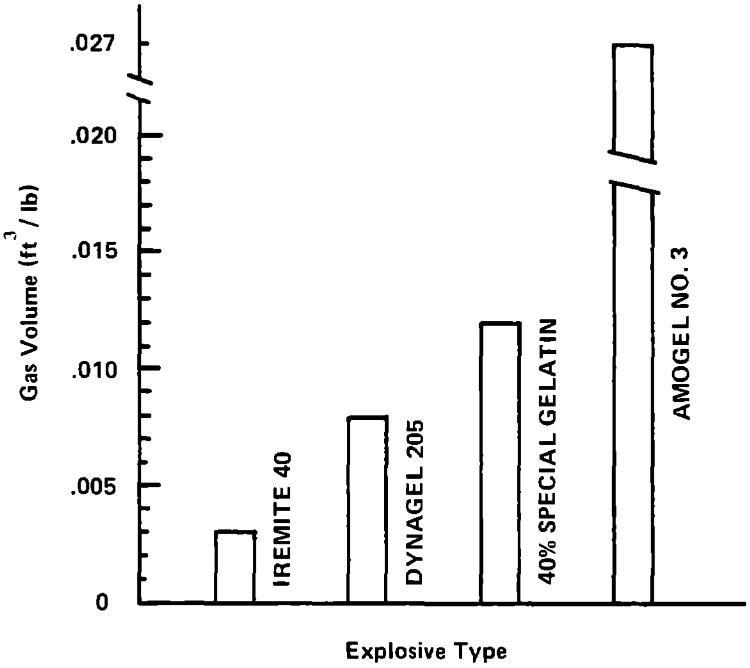


Figure 18. Average Volume of Ammonia Produced by Each Explosive

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APPENDIX A

Computed Gas Values in Units of Liters/Kilogram and Cubic Feet/200 Grams

Table A-1. Calculated Gas Volume Produced by IREMITE 40, Water Gel Explosive

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume (1/kg)					
			NO	NO_2	CO	SO_2	NH_2	CO_2
9	52.93	4343	(a)	(a)	4.37	0.062	0.187	102.37
10	52.93	4590	(a)	(a)	7.49	0.125	0.250	144.82
11	50.96	4802	(a)	(a)	4.37	0.062	0.187	97.37
12	52.93	5049	(a)	(a)	4.37	0.062	0.187	81.77
13	52.93	5296	(a)	(a)	3.75	0.062	0.187	88.89
14	52.93	5296	(a)	(a)	4.37	0.062	0.187	124.85
15	52.93	5755	(a)	(a)	5.62	0.125	0.250	140.45
16	52.93	5967	(a)	(a)	6.24	0.125	0.250	124.85
		Mean	(a)	(a)	5.08	0.086	0.211	113.17
		Standard Deviation	(a)	(a)	1.18	0.030	0.030	22.25

(a) Oxides of nitrogen not measured due to limited detection range of TECO Analyzer

Table A-2. Calculated Gas Volume Produced by AMOGEL NO. 3, Semigeltin Dynamite

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume (1/kg) NO	NO_2	CO	SO_2	NH_2	CO_2
26	59.22	8686	4.37	4.37	32.46	0.38	1.87	516.86
27	60.48	8898	5.62	4.99	26.84	0.38	1.87	418.23
28	57.96	9075	6.87	9.36	31.21	0.38	1.87	468.17
29	59.22	9287	4.99	6.24	(a)	(a)	(a)	(a)
30	58.38	9498	5.62	8.11	32.46	0.50	1.87	509.37
31	56.70	9675	4.99	8.11	27.47	0.31	1.25	493.14
32	59.64	9887	(b)	(b)	(b)	(b)	(b)	(b)
41	55.44	12217	2.50	3.75	18.10	0.44	1.25	219.73
		Mean	4.99	6.42	28.09	0.40	1.66	437.58
		Standard Deviation	1.25	1.99	4.99	0.06	0.29	102.71

(a) Values too erratic; values did not peak or reach equilibrium

(b) Mixing fan in test drift failed

Table A-3. Calculated Gas Volume Produced by DYNAGEL 205, Water Gel Explosive

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume (l/kg) NO	NO_2	CO	SO_2	NH_2	CO_2
33	55.46	10134	2.50	1.25	9.99	0.250	0.560	206.00
34	59.00	10275	2.50	1.87	9.99	0.187	0.499	263.42
35	60.18	10522	2.50	1.25	8.11	0.187	0.187	222.23
36	54.87	10770	2.50	1.87	7.49	0.187	0.437	184.77
37	54.87	10981	(a)	(a)	(a)	(a)	(a)	(a)
38	57.82	11229	2.50	1.87	9.36	0.250	0.624	141.07
39	54.87	11546	2.50	1.87	6.24	0.187	0.375	161.05
40	58.41	11899	1.87	1.25	8.74	0.187	0.499	176.03
		Mean	2.41	1.60	8.56	0.205	0.454	193.51
		Standard Deviation	0.22	0.31	1.28	0.028	0.132	37.90

(a) Mixing fan in test drift not operating

Table A-4. Calculated Gas Volume Produced by 40% SPECIAL GENLATIN, Gelatin Dynamite

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume (l/kg) NO	NO_2	CO	SO_2	NH_2	CO_2
42	73.14	12570	5.62	1.87	13.73	0.187	0.562	159.80
43	65.19	12888	8.11	2.50	14.98	0.250	0.811	156.06
44	58.83	13206	9.36	2.50	13.11	0.187	0.499	138.58
45	57.24	13449	8.74	3.75	16.85	0.250	0.874	194.76
46	58.30	13877	10.71	1.87	14.36	0.312	0.998	131.09
47	58.83	14230	8.74	2.50	16.22	0.312	0.874	124.85
48	57.77	14548	11.24	2.50	13.11	0.250	0.749	88.64
49	57.77	14901	8.74	2.50	15.61	0.250	0.811	117.35
		Mean	8.91	2.50	14.75	0.250	0.772	138.89
		Standard Deviation	1.60	0.54	1.32	0.044	0.156	29.79

Table A-5. Calculated Gas Volume Produced by IREMITE 40, Water Gel Explosive

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume (ft^3/200 x 10^2 g)					
			NO	NO_2	CO	SO_2	NH_2	CO_2
9	52.93	4343	(a)	(a)	3.08	0.044	0.132	72.24
10	52.93	4590	(a)	(a)	5.29	0.088	0.176	102.19
11	50.96	4802	(a)	(a)	3.08	0.044	0.132	68.72
12	52.93	5049	(a)	(a)	3.08	0.044	0.132	57.71
13	52.93	5296	(a)	(a)	2.64	0.044	0.132	63.43
14	52.93	5508	(a)	(a)	3.08	0.044	0.132	88.10
15	52.93	5755	(a)	(a)	3.96	0.088	0.176	99.11
16	52.93	5967	(a)	(a)	4.41	0.088	0.176	88.10
		Mean	(a)	(a)	3.58	0.060	0.149	79.95
		Standard Deviation	(a)	(a)	0.84	0.021	0.021	15.60

(a) Oxides of nitrogen not measured due to limited detection range of TECO Analyzer

Table A-6. Calculated Gas Volume Produced by AMOGEL NO. 3, Semigelatin Dynamite

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume ($ft^3/200 \times 10^2$ g)					
			NO	NO_2	CO	SO_2	NH_2	CO_2
26	59.22	8686	3.08	3.08	22.91	0.264	1.322	364.73
27	60.48	8898	3.96	3.52	18.94	0.264	1.322	299.49
28	57.96	9075	4.85	6.61	22.03	0.264	1.322	330.37
29	59.22	9287	3.52	4.41	(a)	(a)	(a)	(a)
30	58.38	9498	3.96	5.73	22.91	0.352	1.322	359.44
31	56.70	9675	3.52	5.73	19.38	0.220	0.881	347.99
32	59.66	9887	(b)	(b)	(b)	(b)	(b)	(b)
41	55.44	12217	1.76	2.64	12.77	0.308	0.881	155.06
		Mean	3.52	4.53	19.82	0.279	1.175	309.51
		Standard Deviation	0.88	1.41	3.53	0.041	0.208	72.36

(a) Values too erratic; values did not peak or reach equilibrium

(b) Mixing fan in test drift failed

Table A-7. Calculated Gas Volume Produced By DYNAGEL 205, Water Gel Explosive

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume ($ft^3/200 \times 10^2$ g)					
			NO	NO_2	CO	SO_2	NH_2	CO_2
33	55.46	10134	1.76	0.88	7.05	0.176	0.396	145.36
34	59.00	10275	1.76	1.32	7.05	0.132	0.352	185.89
35	60.18	10522	1.76	0.88	5.73	0.132	0.132	156.82
36	54.87	10770	1.76	1.32	5.28	0.132	0.308	130.38
37	54.87	10981	(a)	(a)	(a)	(a)	(a)	(a)
38	57.82	11229	1.76	1.32	6.61	0.176	0.441	99.55
39	54.87	11546	1.76	1.32	4.41	0.132	0.264	113.58
40	58.41	11899	1.32	0.88	6.17	0.132	0.352	124.22
		Mean	1.69	1.13	6.04	0.144	0.321	136.54
		Standard Deviation	0.15	0.22	0.90	0.020	0.093	26.75

(a) Mixing Fan in test drift not operating

Table A-8. Calculated Gas Volume Produced By <u>40% SPECIAL GELATIN</u>, Gelatin Dynamite

Experiment No.	Explosive Amount (lbs)	Containment Volume (ft^3)	Gas Volume ($ft^3/200 \times 10^2$ g)					
			NO	NO_2	CO	SO_2	NH_2	CO_2
42	73.14	12570	3.96	1.32	9.69	0.132	0.396	112.76
43	65.19	12888	5.73	1.76	10.57	0.176	0.573	110.13
44	58.83	13206	6.61	1.76	9.25	0.132	0.352	97.79
45	57.24	13559	6.17	2.64	11.89	0.176	0.617	137.43
46	58.30	13877	7.49	1.32	10.13	0.220	0.705	92.51
47	58.83	14230	6.17	1.76	11.45	0.220	0.617	88.10
48	57.77	14548	7.93	1.76	9.25	0.176	0.528	62.55
49	57.77	14901	6.17	1.76	11.01	0.176	0.573	82.81
		Mean	6.28	1.76	10.41	1.76	0.545	98.01
		Standard Deviation	1.12	0.38	0.93	0.03	0.110	21.01