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ATMOSPHERIC DIFFUSION OF BERYLLIUM (PROJECT ADOBE)

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TECHNICAL REPORT AFRPL-TR-70-65-VOL. I

JULY 1971

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A field study of exhaust cloud diffusion from solid rocket motors was conducted at the Air Force Rocket Propulsion Laboratory. The objective of the program was to correlate the diffusion of rocket motor exhaust clouds with measurable meteorological variables under both stable and unstable atmospheric conditions. Fifty-seven sets of field data were collected from 250 to 350 air samplers per test using solid rocket motors ranging from 100 to 4000 pounds of propellant containing beryllium. The work is presented in three volumes. Volume I describes the diffusion experiment, the chemical analysis program, the bioenvironmental safety program, and discusses the data analysis and the resulting diffusion equations from hot instantaneous sources. Volume II presents tabulations of the diffusion and meteorological data. Volume III presents the cloud-tracking data.

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EDWARDS, CALIFORNIA

FOREWORD

This is the final report for a development program sponsored, directed and conducted by the Air Force Rocket Propulsion Laboratory, Air Force Systems Command, Edwards Air Force Base, California, under Project No. 305999099 and 305907024, on the study of the diffusion of puff-type exhaust clouds generated during the firing of solid rocket motors. It covers the technical achievements of the motor test meteorological program from 1 April 1964 through 1 November 1967, the re-suspension tests through June 1968 and the analysis of data through February 1970. A total of $217, 285 of the Laboratory Director's funds were expended-$142, 000 FY64 and $75, 285 FY65.

This project was initiated at the direction of Colonel Joseph Silk and was terminated at the direction of Colonel Elwood M. Douthett.

Authors of the various sections of this report are:

SECTION I	SUMMARY (by Hugh E. Malone)
SECTION II	INTRODUCTION (by Hugh E. Malone)
SECTION III	DIFFUSION EXPERIMENT (by Hugh E. Malone and Gordon L. Tucker, Maj, USAF)
SECTION IV	CHEMICAL ANALYSIS TECHNIQUES (by Michael F. Citro and Einar Enwall)
SECTION V	DATA ANALYSIS (by Gordon L. Tucker, Maj, USAF and Robert W. Smith, Capt, USAF)
SECTION VI	BIOENVIRONMENTAL ENGINEERING PROGRAM (by David C. Beatty, Maj, USAF)

This technical report has been reviewed and is approved.

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ABSTRACT

A field study of exhaust cloud diffusion from solid rocket motors was conducted at the Air Force Rocket Propulsion Laboratory. The objective of the program was to correlate the diffusion of rocket motor exhaust clouds with measurable meteorological variables under both stable and unstable atmospheric conditions. Fifty-seven sets of field data were collected from 250 to 350 air samplers per test using solid rocket motors ranging from 100 to 4000 pounds of propellant containing beryllium. The work is presented in three volumes. Volume I describes the diffusion experiment, the chemical analysis program, and the bioenvironmental safety program, and discusses the data analysis and the resulting diffusion equations from hot instantaneous sources. Volume II presents tabulations of the diffusion and meteorological data. Volume III presents the cloud-tracking data.

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SECTION I

SUMMARY

An atmospheric diffusion program was conducted at the Air Force Rocket Propulsion Laboratory (AFRPL) over a 25 square mile area arrayed with 492 air samplers. Sixty-five solid rocket motors containing beryllium were test fired under both stable and unstable meteorological conditions. Fifty-seven sets of meteorological data on wind speed, wind direction and temperature lapse rate, together with beryllium integrated concentration data as determined from the air samplers by chemical analysis, were collected, reduced and used in a regression analysis study, and a series of diffusion equations was developed for hot, quasi-instantaneous releases.

These equations, in their nonlogarithmic form (page 48), can be used operationally to determine either peak exposure, distance or source strength of toxic particles from rocket motor exhausts. AFRPL demonstrated that large rocket motors could be used as gas generators of toxic hazardous traces in a diffusion program and that the program could be conducted safely despite complex details involving multidisciplined people, toxic rocket motor tests, and rigorous test operational procedures under selective meteorological conditions.

The chemical analysis procedures, design of the diffusion experiment and bioenvironmental practices are described.

Finally, the chemical, meteorological and cloud-tracking data are presented to allow further analysis and interpretation.

SECTION II

INTRODUCTION

In April 1964, a field program designed to extend knowledge of beryllium contaminant dispersion from ground level sources was initiated at the Air Force Rocket Propulsion Laboratory (AFRPL), Edwards, California. The program was called "Project ADOBE," an acronym for atmospheric diffusion of beryllium.

The primary objective was to develop applicable techniques for predicting the distribution of downwind concentrations of beryllium pollutant from rocket motor exhausts.

Earlier, the Air Force Cambridge Research Laboratory (AFCRL) sponsored and directed a field data collection diffusion program at O'Neill, Nebraska, in 1956 called Prairie Grass (ARDC Project 7657) (Reference 1). The objective of this study was to determine the rate of diffusion of a tracer gas (SO_2) as a function of meteorological conditions out to distances of 800 meters from the source. A second series of field experiments, extending Project Prairie Grass, was conducted in 1959 at the General Electric Company's Hanford Atomic Products Operation, Richland, Washington, as part of the Nuclear Safety Program (ARDC Project 8644). This project, called Project Green Glow (Reference 2), consisted of 26 night experiments to determine horizontal and vertical diffusion patterns as a function of meteorological conditions. Zinc sulfide was used as a tracer and particulate samples were collected out to distances of 25,600 meters from the source. The knowledge obtained from these programs permitted AFCRL to design and conduct diffusion studies in 1961 and 1962 in support of Titan II operations at Vandenberg AFB and Cape Kennedy. These programs were known as Ocean Breeze (Reference 3) and Dry Gulch (Reference 4) and involved the measurement of releases of particulate zinc sulfide at a constant rate for 30 minutes out to distances of 3 miles at both Cape Kennedy and Vandenberg AFB. The diffusion data collected was incorporated with the data obtained from Project Prairie Grass to derive diffusion equations for both the Ocean Breeze and Dry Gulch programs. Since the data obtained was from ground-level continuous cold sources, it was unsuitable for investigating the basic mechanism of turbulent diffusion resulting from hot quasi-instantaneous rocket motor releases. As a result, Project Sandstorm (AFRPL Task 385001001) (Reference 5), sponsored by AFRPL and directed by AFCRL was conducted in 1962 at AFRPL. Small solid rocket motor grains ranging from 8 to 65 pounds were used to provide a beryllium tracer under unstable conditions only. The rocket motor exhaust products were captured out to distances of 2400 meters.

Since the problem of extrapolation of diffusion data was questionable because of meteorological conditions as well as motor size, Project ADOBE was initiated to extend the Sandstorm experiment for both increased beryllium motor sizes (4000 pounds) and measurement of toxic exhausts on a diffusion grid out to a distance of 6 miles (9600 meters). Concurrently, another puff-type exhaust cloud diffusion study using beryllium as a tracer was being conducted in 1965 and 1967 at the Aerojet-General Corporation Facility at Lovelock, Nevada (Reference 6). The tests were conducted under stable (neutral and inversion) atmospheric conditions and diffusion data was collected out to 30 miles from the source. For the ADOBE program, beryllium dosage measurements were made under both stable and unstable atmospheric conditions at a height of 1.5 meters at distances of 600 meters, 1200 meters, 2400 meters, 4800 meters and 9600 meters. Air samples were collected at 492 sampling positions. Meteorological measurements were made on a 204-foot tower with wind speed, wind direction and temperature gradient instruments at the 12-, 50-, 100- and 200-foot levels.

Three types of tests formed the basis of the Project ADOBE test program:

(1) Motor tests using solid rocket motors ranging from 100 to 4000 pounds of propellant

(2) Burn tests using quantities of unconfined propellant

(3) Contamination tests conducted at 2, 24 or 48 hours after release of the tracer material

The burn tests conducted to determine the particle size, particle shape and beryllium-to-beryllium oxide ratios at ambient pressures were not completed and will not be discussed in this report. The diffusion data presented herein was obtained from exhausts emitted from confined, high-pressure (300 to 1000 psi) solid rocket motors. The contamination test data was incorporated as subtractive values from individual diffusion tests.

The design and manner of conducting the experiment were provided with the assistance of AFCRL. Managing of the experiment and collection of chemical, photographic and mechanical data were provided by AFRPL. Data reduction was done at AFRPL by TSI Corporation.

The following personnel were directly involved in the ADOBE diffusion program:

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Forrest Hughes, Captain
Robert W. Smith, Captain

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Leo Bongiovanni
Richard Marco
Vernon Christenson
John Lynch
Fred Rambus

The objectives of this report are to describe the experiment, instrumentation, source of tracer, air-sampling system, and chemical and meteorological treatment of the data, and finally, to analyze and develop a mathematical diffusion equation for quasi-instantaneous releases of beryllium from rocket motors. The report will be in three volumes. Volume I will contain a detailed description of the above items, Volume II will contain the meteorological data and tabulations of the diffusion data, and Volume III will contain the cloud-tracking data.

SECTION III
DIFFUSION EXPERIMENT

Air samples were obtained from 64 solid rocket motors containing beryllium. The motors ranged from 100 to 4000 pounds. The tests were conducted under both stable (neutral and inversion) and unstable atmospheric conditions.

DESCRIPTION OF FACILITY

The toxic hazard diffusion facility of the Air Force Rocket Propulsion Laboratory is located in San Bernardino County, 14 miles east of Edwards AFB, 8 miles south of Boron, and 9.5 miles south-southwest of Kramer Junction. The diffusion area extends in an east-northeast direction for approximately 17 miles provided Highway 395 (which bounds the area on the east) is controlled during test operations. The elevation ranges from 3000 to 3400 feet. The yearly rainfall is 2 to 6 inches, temperature ranges from 18°F in the winter to 110°F in the summer and the wind direction is predominantly from the southwest.

DIFFUSION SAMPLING GRID

The diffusion grid covers 25 square miles and is laid out in a 90-degree sector (Figure 1). The grid contains 8 arcs of air samplers (a total of 492), surveyed and located as shown in Table I.

Between 250 and 350 air samples were obtained during each test. For the 4000-pound solid rocket motors, the air samplers on the 600-, 2400-, 4800-, and 9600-meter arcs were generally used.

Access roads were provided for each arc downwind of the samplers. All sampler locations were marked and numbered clockwise with the degree and arc numbers.

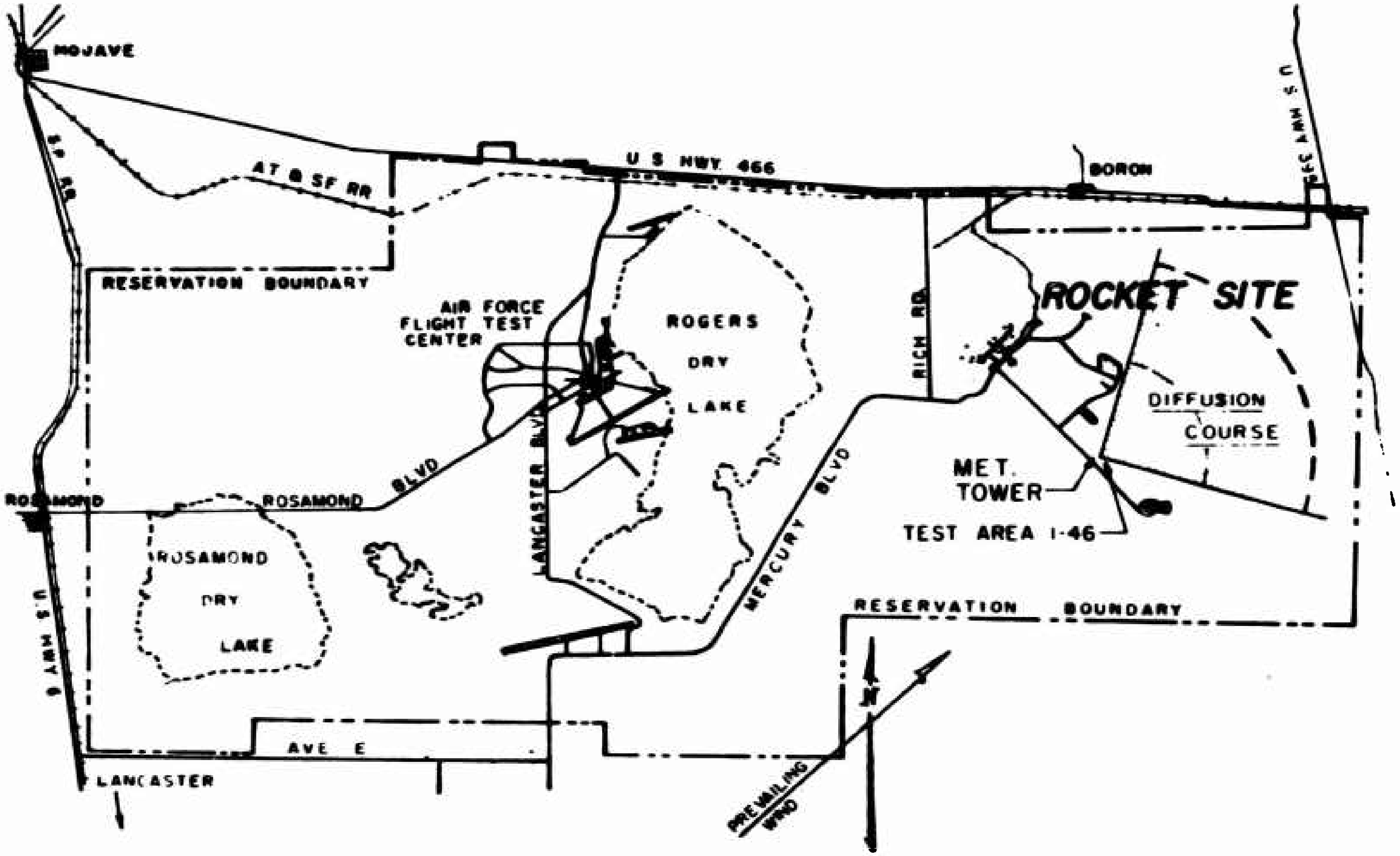

Figure 1. Edwards AFB Vicinity Map

TABLE I. SAMPLING GRID

Arc No.	Location (meters)	No. Samplers	Sampler Spacing
1	100	23	4°
2	300	23	4°
3	600	46	2°
4	800	46	2°
5	1200	61	1.5°
6	2400	61	1.5°
7	4800	91	1.0°
8	9600	91	1.0°
A portable sampler rack		49	3 feet

METEOROLOGICAL INSTRUMENTATION

Meteorological measurements were obtained from instruments mounted on a 204-foot tower adjacent to the motor test pad. Wind speed, wind direction and vertical temperature gradient sensors were located at the 12-, 50-, 100- and 200-foot levels. Table II lists the instruments on the tower and Figures 2 and 3 show the tower and the recorders.

TABLE II. METEOROLOGICAL INSTRUMENTATION

Tower Level (feet)	Instrument	
6	Temperature	L & N*
12	Wind	B & W**
50		L & N; B & W
100		L & N; B & W
200		L & N; B & W

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* Leeds and Northrup copper thermohm Model 8195.

** Beckman and Whitley wind set Model 101.

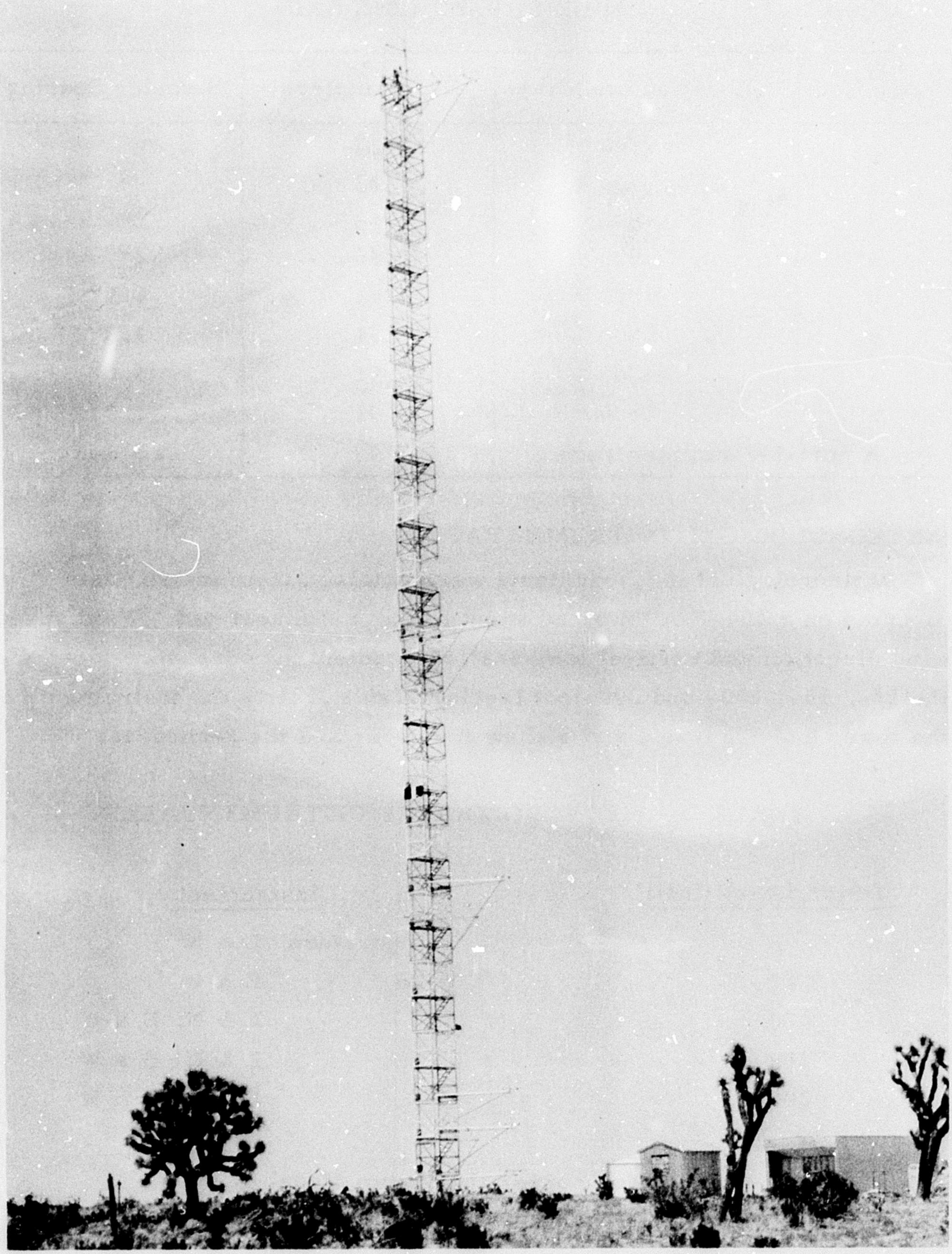

Figure 2. Meteorological Tower

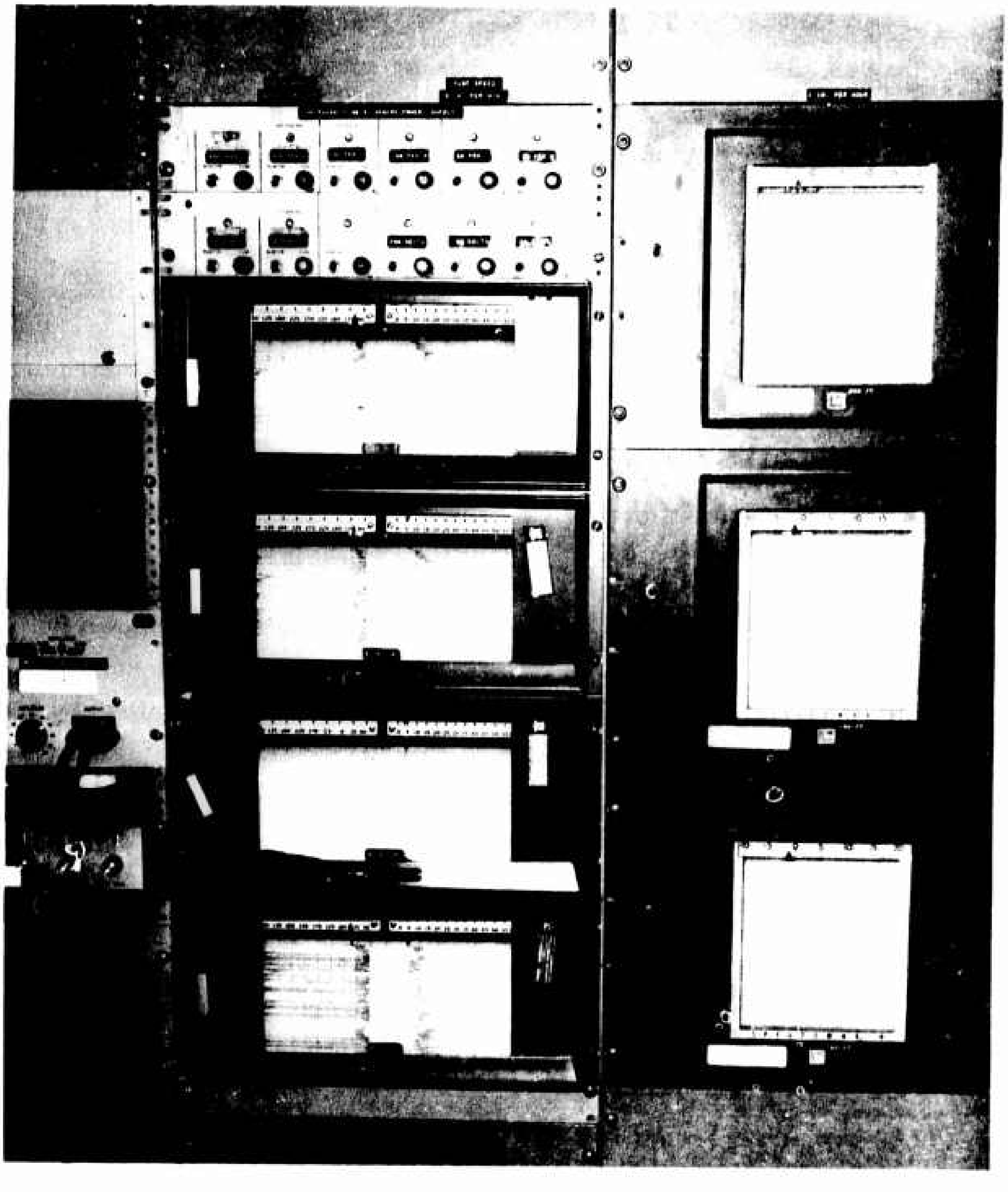

Figure 3. Meteorological Instrumentation Control

Chart speeds for temperature gradient data were 1 in. /hr. For test data collection, the wind recorders were operated at 6 in. /min from T-3 minutes until T+40 minutes. Data from these high-speed recorder traces were used to compute variances of both wind speed and direction for correlation with the exhaust cloud diffusion pattern. Average temperature gradient values were collected for the same time intervals. Phototheodolite data, taken for correlation with the meteorological measurements and diffusion patterns, is presented in Volume III of this report.

AIR SAMPLERS

The air samplers used were manufactured by the Gelman Instrument Company and consist of a 1-horsepower motor and fan which move air at a 4 to 7 cu ft/min flow rate through a 4-inch cellulose nitrate membrane filter (5.0 microns ±1.2 microns pore size) manufactured by the Millipore Corporation. Each filter was supported by a screen to avoid damage to the membrane. To stabilize the air flow, a 1/2-inch orifice was inserted in the sampler exhaust port. A picture of the sampling unit is shown in Figure 4. Each air sampler was powered by two 12-volt, 88-ampere, heavy-duty lead acid batteries in series which could be activated and shut down either manually or remotely. For this experiment, the samplers were controlled remotely by a 10-circuit relay control panel. Two Simpson gauges allowed a voltage and milliampere reading for each arc of samplers. Each sampler relay draws 3 milliamperes, and the entire control system requires 100 vdc. A bank of booster batteries was used at both 4800 and 9600 meters to ensure sufficient power to control the sampler relays on respective arcs. A schematic of the grid wiring is shown in Figure 5 and a picture of the control box is shown in Figure 6.

The samplers were mounted 4 feet above the ground on portable stands. Pre-test and post-test differential pressure measurements were taken for each sample using a Magnehelic Model No. 2005 gauge. The field accuracy

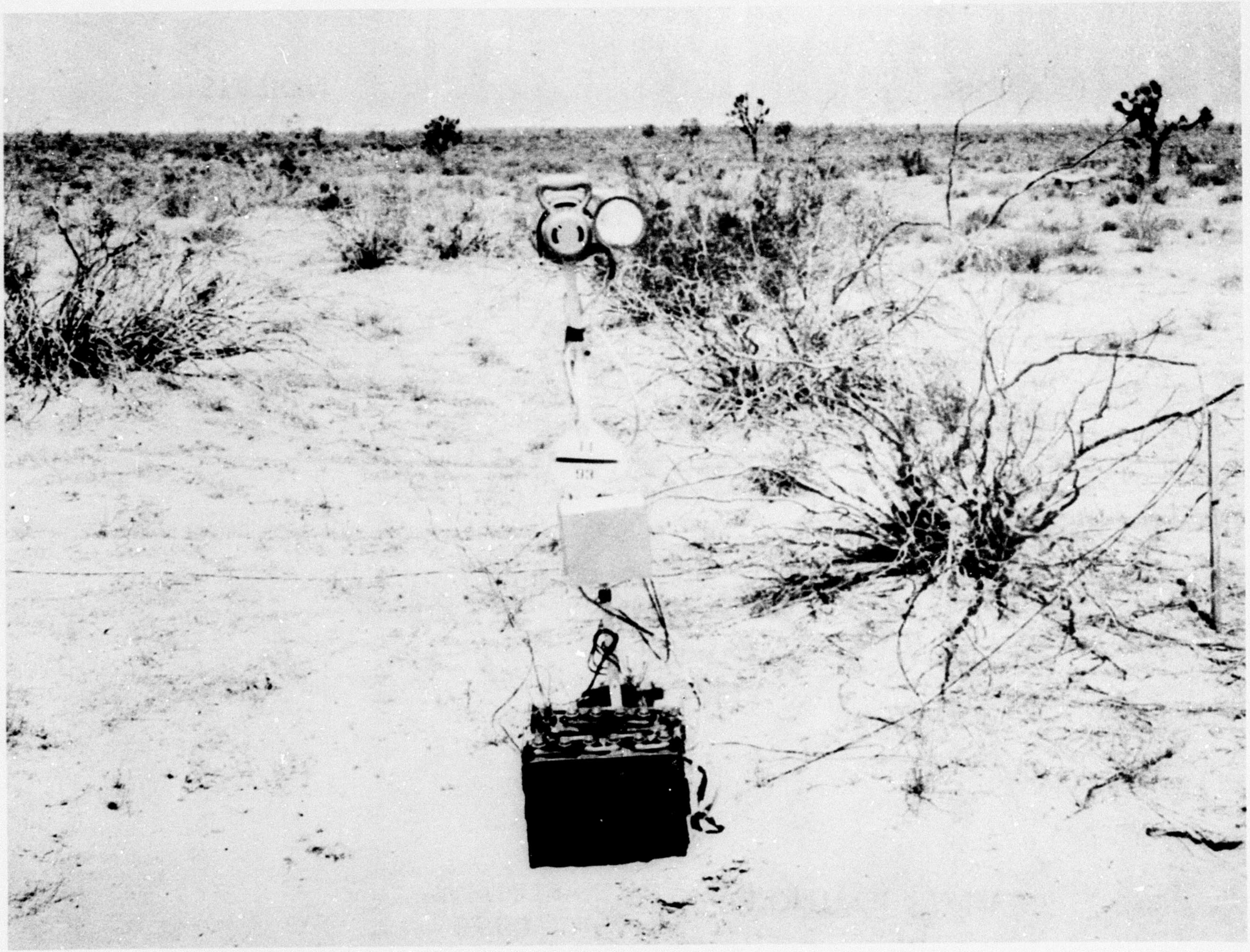

Figure 4. Air Sampler

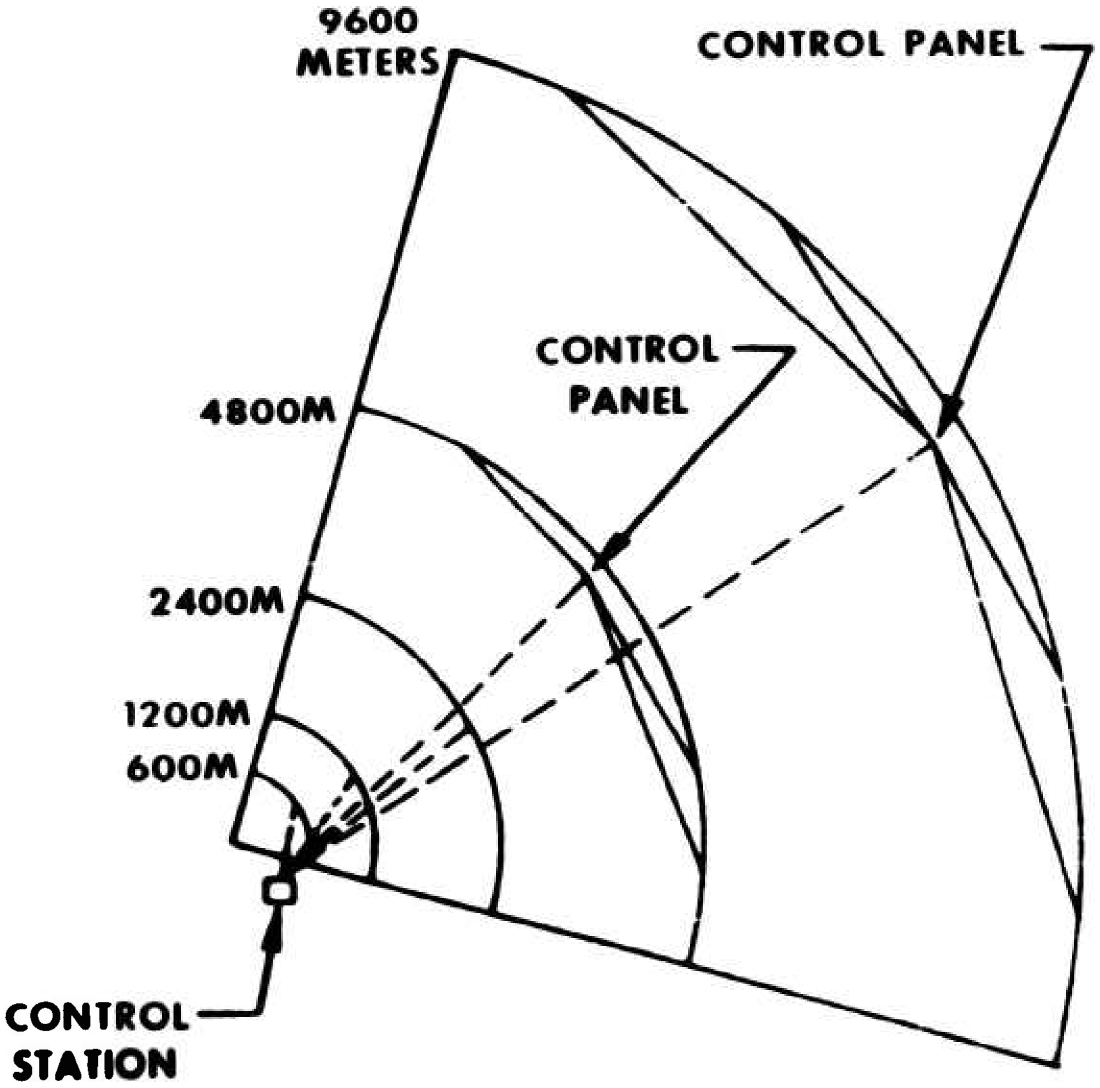

Figure 5. Diffusion Grid Wiring

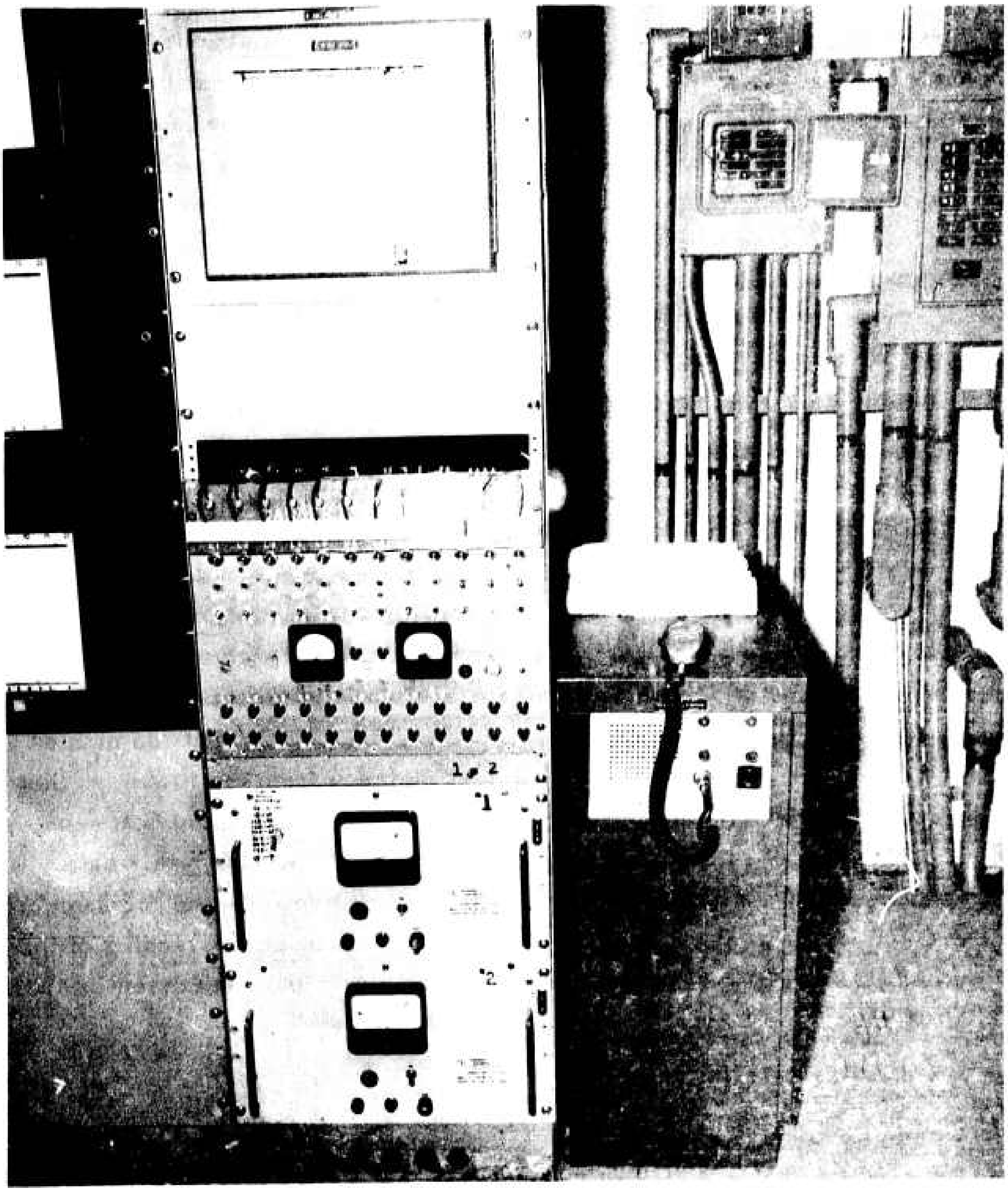

Figure 6. Air Sampler Control Box

of the gauges is ±2 percent full scale. The average flow rate through the samplers was computed from the two pressure measurements, using a mean calibration curve based on a randomly selected sample of approximately one-third of the total number of samplers. The calibration apparatus used is shown in Figure 27 of Section VI of this report. The principal deviations in sampler flow rate were caused by weak batteries and variations in the pore size of the filter membranes. (The latter problem was resolved by 100 percent quality control of each membrane using a standard sampler.)

AIR SAMPLER RACK

An air sampler rack 21 by 21 by 3 feet was fabricated to permit multiple sampling vertically and horizontally through the rocket motor exhaust cloud. The sampler rack shown in Figure 7 was portable and contained 7 rows of 7 air samplers each spaced 3 feet apart (49 samplers total). The rack also contained work platforms to ease sampler maintenance and membrane removal. The samplers were powered by two 440-volt portable rectifiers. The air sampler rack also allowed relatively easy evaluation of multiple samplers, sequential samplers, liquid samplers, etc. Care was exercised in placing the rack so that the plume would pass through it but at a sufficient distance from the motor so that the samplers would be undamaged. Most data was collected between 50 and 100 meters downstream from the motors. Although this data was of some importance in terms of motor performance and for sampler evaluation, it did not contribute significantly to the understanding of the diffusion process and is mentioned here solely to show the extent of the air-sampling system.

SAMPLE HANDLING

Since all filter membranes contain contaminated beryllium exhaust products after firing, extreme care was taken in handling the filter membranes and also in protecting the ADOBE diffusion crew. All contaminated

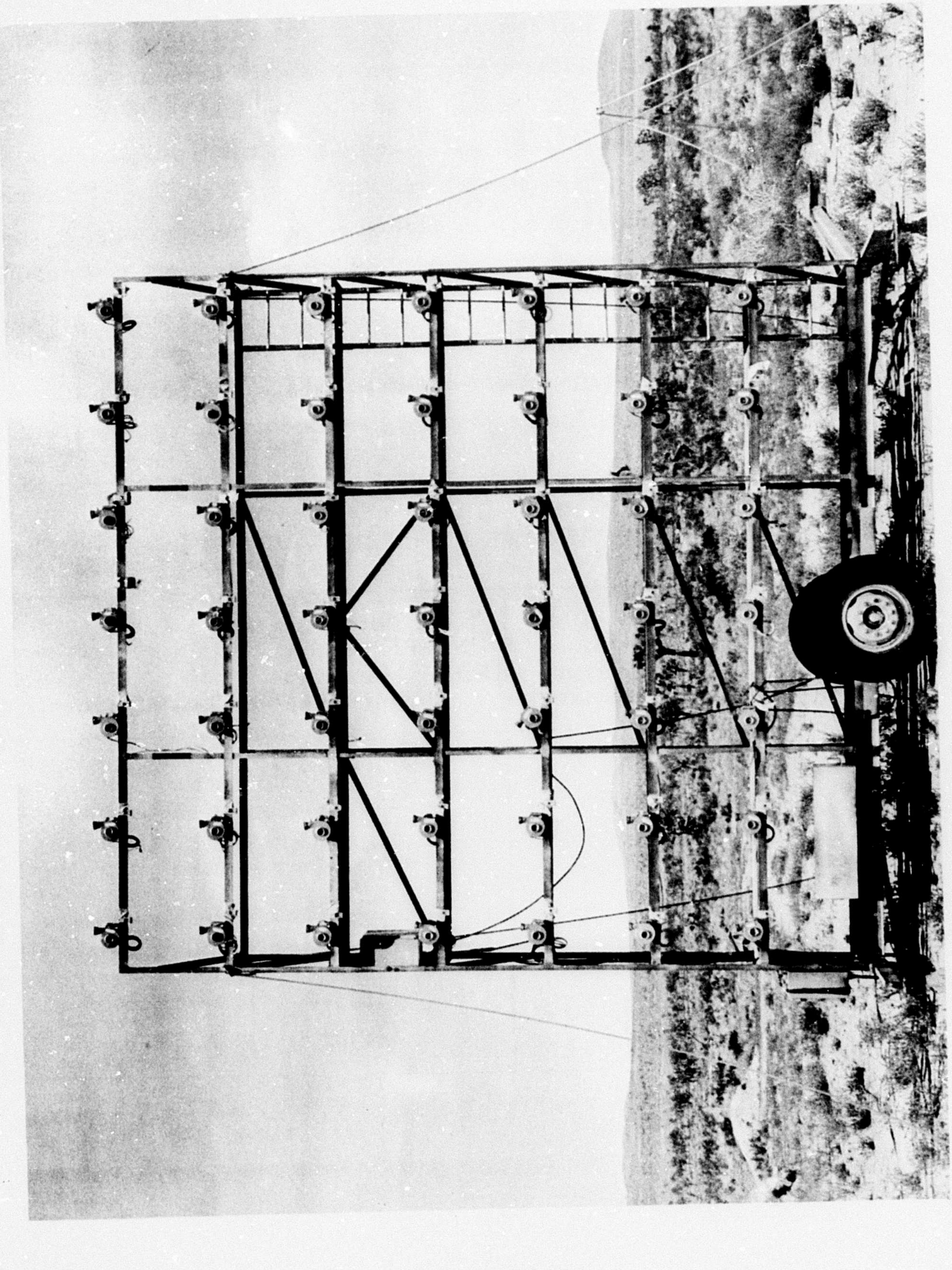

Figure 7. Portable Sampler Rack

sampler filter holders were immediately, placed in polyethylene bags and numbered for sampler position, test number, and date of test. The bags were sealed and the filter holders were taken to a work area containing ventilation hoods. The filter holders were dismantled and the filter membranes were replaced in the marked bags, resealed, and transported to the chemistry laboratory for processing and analysis. The filter holders were washed on the apparatus shown in Figure 8 and dried thoroughly, refilled with new filter membranes and readied for the next test. Because of the handling of the filter membranes in the polyethylene bags and the possibility that beryllium particles could be rubbed off, an experiment was conducted to determine the amount of beryllium loss. The results shown in Table III indicate that less than 4 percent loss occurred.

TABLE III. BERYLLIUM LOSS FROM MEMBRANE HANDLING

Sample No.	Total Beryllium Recovered from Bag (micrograms)	Total Beryllium Determined on Filter Membrane (micrograms)	Loss (percent)
1	71.1	2,680	2.6
2	338.0	22,800	1.2
3	241.2	7,460	3.2
4	300	6,960	4.3
5	316	17,775	1.8
6	278	12,000	2.3
7	102	4,125	2.5
8	126	4,440	2.8

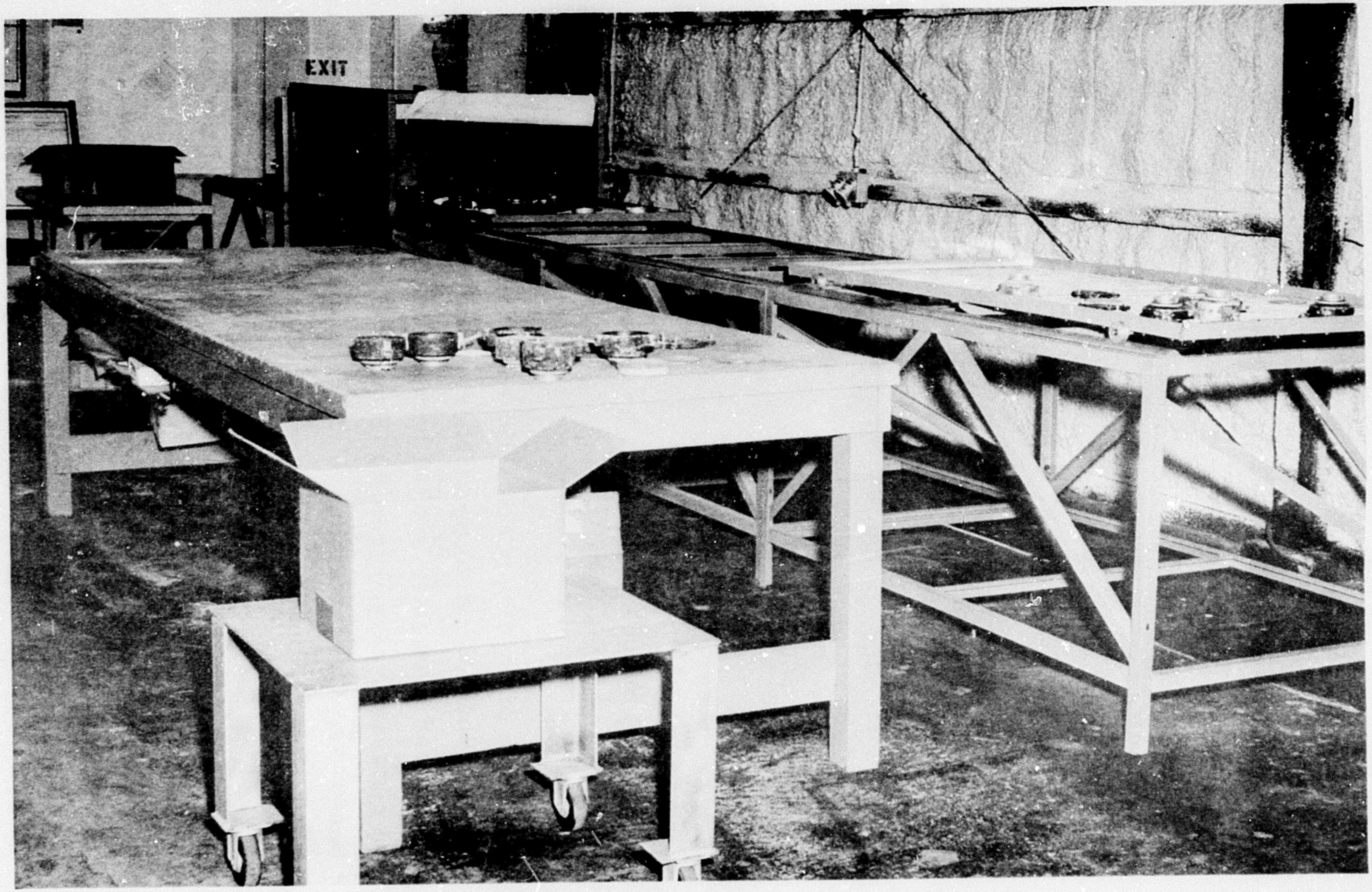

Figure 8. Filter Holder Wash Rack

TEST MOTORS

Solid propellant rocket motors ranging from 100 to 4000 pounds and containing beryllium propellant as a tracer source were test fired in a horizontal position. Two other motors containing aluminum and weighing 6500 pounds were also tested. The size and number of each motor shown in Table IV.

TABLE IV. SOLID ROCKET MOTORS TESTED

No. of Tests	Motor Size (pounds)	Duration (seconds)	No. of Air Samples
26	100 to 200	26 to 30	5600
17	400 to 600	12 to 35	4000
19	3000 to 4000	45 to 60	7000
2	6500	45 to 60	600

Typical solid motors used as gas generators for the beryllium tracer are shown in Figures 9 and 9a.

Twenty-five of the 100-pound solid rocket motors were test fired under stable (neutral and inversion) atmospheric conditions. These conditions were experienced from 0430 to 0730 hours from October 1965 to July 1966. The lapse conditions ranged from +1°F to +5°F with wind speeds ranging from 5 to 20 mph. The remaining solid rocket motors were test fired under unstable atmospheric conditions between 0900 and 1600 hours.

Two test stands rated at 10,000 and 75,000 pounds of thrust and separated by an earth-filled revetment were used during the motor tests. These stands were mounted on concrete pads which extended 30 feet aft of the nozzle. Wash water drained to a sump tank below the pad and, from there, to an open-ended steel holding tank approximately 200 feet from the stand. Water from this tank leached into the soil.

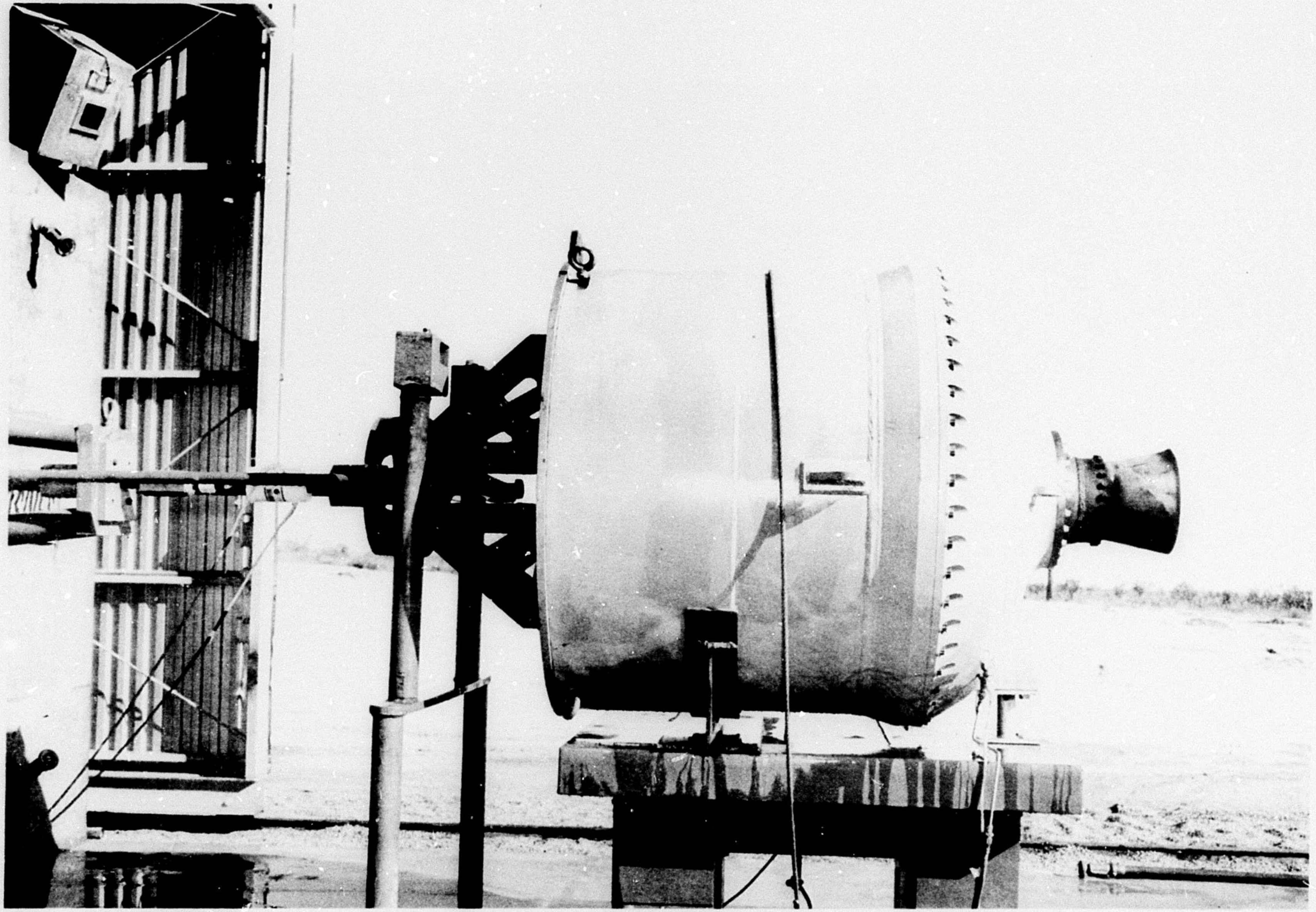

Figure 9. Rocket Motor

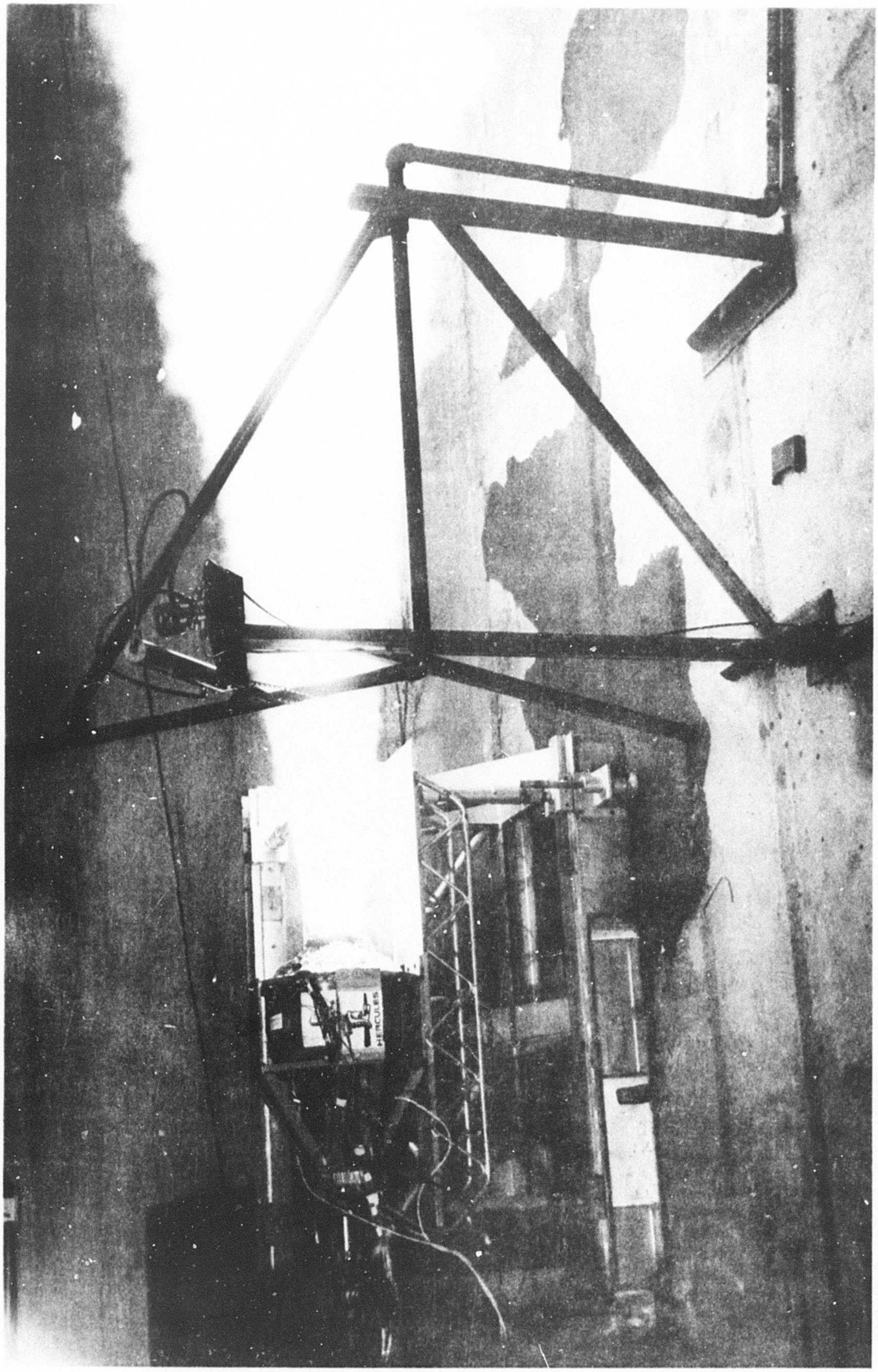

Figure 9a. Rocket Motor Firing

SAFETY

All personnel working on the program were provided with annual physical examinations. During work on the contaminated diffusion grid, personnel were required to wear white protective coveralls and respirators. This protective clothing was worn only during the time spent on the diffusion grid or during the handling of contaminated air-sampler heads. Shower facilities were provided daily. A field shower facility was also provided for all vehicles traversing the diffusion grid area. An expanded description of the safety practices employed during this program is presented in Section VI.

SECTION IV

CHEMICAL ANALYSIS TECHNIQUES

The analytical chemistry requirements of Project ADOBE were directed toward analyzing diffusion and re-entrainment samples in the form of airborne dust, soil and work area contamination (wipe) samples. In addition, effort was directed toward the identification and analysis of such solid rocket propellant exhaust species as beryllium chloride ($BeCl_2$), beryllium hydroxide ($Be(OH)_2$), ammonium chloride (NH_4Cl), hydrogen chloride (HCl) and chlorine (Cl_2) (Reference 7). To maintain the integrity during separation and analysis of these compounds, several unique sampling and analysis schemes were developed. Midget impingers containing either N-methyl pyrrolidineone (a nonaqueous solvent) or dilute sodium hydroxide were used for gases and minute particles.

High-volume "hurricane" air samplers fitted with 4-inch cellulose acetate membrane filters were used for airborne particles and adhesive paper (12 by 12 inches Simon Adhesive Company) was used for soil or surface samples.

Particulate count, size and total beryllium were determined from the filter membranes. Total chloride content, free chlorine, ammonium ion and total beryllium were determined from the aqueous sodium hydroxide impinger solutions. Soluble beryllium chloride, hydrochloric acid and insoluble beryllium oxide were determined from the N-methyl pyrrolidineone impinger solutions.

The beryllium content of the samples was determined by the Morin-fluorometric method (Reference 8 and 9).

Beryllium reacts with Morin (2', 4', 3, 5, 7 pentohydroxy flavone) in an alkaline solution to produce a compound that fluoresces when energized by ultraviolet radiation. Interferences from fluorescent compounds of other metals, such as lithium, scandium, zinc, calcium and others, are eliminated by addition of a complexing agent (EDTA), making the Morin reaction nearly specific for beryllium. The results from 21 artificial standards containing 0.1 to 35 micrograms of beryllium indicated that the average relative deviation of the Morin fluorescence method was 2.56 percent. The minimum detectable limit is 0.001 microgram of beryllium

Near the end of the ADOBE program, an atomic absorption spectrophotometric method was developed and used. The analytical results are included as part of the exposure data in Volume II of this report.

EXPERIMENTAL

Large numbers of diffusion samples were collected and analyzed. Many of these contained beryllium levels of <0.02 microgram. The Morin fluorometric method was conducted rapidly with high sensitivity; however, the filter membrane organic matrix interfered with the determination of beryllium content. As a result, extra time-consuming steps had to be adopted to eliminate the interferences.

Air Samples (Diffusion)

The filter membrane was decomposed and the metal was dissolved by wetting the sample with 2 ml of 36N sulfuric acid to partially char the filter membrane. This step was followed by the addition of 15 ml of 16N nitric acid. The volume of the mixture was reduced on a hot plate to several milliliters and approximately 10 grams of powdered potassium perchlorate ($KClO_4$) were added. The mixture was strongly heated over a Meeker burner until a clear solution (approximately 0.5 to 1.0 ml) was obtained. The solution was quantitatively transferred to a 100 ml volumetric flask and diluted to volume with water.

Area Contamination Samples (Air or Wipe)

Since these samples were taken for industrial hygiene purposes and usually were much lower in beryllium content than the diffusion samples, they were handled separately to prevent cross-contamination. Each filter membrane was placed in a "Vycor" crucible, wetted with 36N sulfuric acid, and then placed in a muffle furnace set to 525 to 550°C, and heated for 4 hours. To ensure complete solution of the beryllium, 5 to 7 drops of 36N sulfuric acid were added to the sample and the mixture was heated further over a Meeker burner until dense white fumes appeared. The resulting clear solution was quantitatively transferred to a volumetric flask (25 ml) and diluted to the mark with distilled water.

Soil Samples (Adhesive)

Surface soil samples were obtained with 1 sq ft sections of adhesive film. The soil and adhesive were separated from the support with toluene (dichloromethane was substituted later). The toluene solvent was evaporated and 25 ml of 36N sulfuric acid were added to the residue. This mixture was heated strongly and the heating was continued for approximately 15 minutes after dense white fumes appeared. The sample, now containing dissolved beryllium, sand and some organic material, was cooled and diluted to 1000 ml. An aliquot of the supernatant liquid was destroyed in the manner described for diffusion samples.

Soil Samples (Subsurface)

One hundred grams of soil were combined with 25 ml of 36N sulfuric acid and the mixture was heated strongly until dense white fumes were evolved. The mixture was cooled and diluted to 1000 ml. A portion of the supernatant liquid was analyzed directly, or after further dilution, by atomic absorption spectrophotometry. For the latter technique, further processing was unnecessary since organic material and the ordinary acid soluble constituents of soil did not interfere.

FLUOROMETRIC ANALYSIS

A sample aliquot of <5 ml and containing 0.0 to 3.0 micrograms of beryllium was pipetted into a 15-ml centrifuge tube. If the sample contained large amounts of calcium (as in Soil Samples), this interfering cation was removed by adding in turn two drops of phenol red indicator, 0.5 ml of 0.3M aluminum nitrate, 1 ml of 25 percent ammonium chloride sufficiently filtered 1:3 ammonium hydroxide to precipitate aluminum and beryllium hydroxide, and diluting to 10 ml with water. The mixture was then centrifuged for 20 minutes at 1600 rpm and the supernatant liquid was discarded. The precipitate was dissolved in 0.1N sulfuric acid. Then 1 ml of 5 percent HEDTA/5 percent EDTA solution was added, followed by 2 drops of phenol red. If the sample contained only small amounts of calcium (as in diffusion or wipe samples), the precipitation/acidification step was omitted and 1 percent HEDTA/5 percent EDTA solution was substituted. The sample from either source (low or high calcium) was made alkaline with a 2-ml excess of buffer solution. This mixture was diluted to 10 ml with water and temperature adjusted to $25 \pm 0.5^{\circ}C$ in a constant temperature bath. One ml of Morin indicator was added and the fluorescence of the sample was determined with a fluorometer. All fluorescence determinations were referenced to a reagent blank. Table V describes the fluorometer instrument analysis conditions.

Standardization

Three calibration curves are prepared.

(1) Curve No. 1 for 0 to 0.08 micrograms of beryllium:

Place millipore filters in 14 100-ml narrow-mouthed Erlenmeyer flasks. With a microburette, transfer volumes of 0.1 microgram of Be/ml solution to the flasks to give the following concentrations: 0, 0.005, 0.01, 0.02, 0.03, 0.05, and 0.07 microgram Be. Treat these standards in the same way as the samples. Set slit at 3 X. Place filters 2A and 47B in the primary position, and filters 58 and 2A-12 in the secondary position.

TABLE V. FLUOROMETRIC INSTRUMENTAL CONDITIONS

Beryllium Range (micrograms)	Filters (Wratten)	Slit
0.00 to 0.05	P = 2A, 47B S = 58, 2A-12	3X
0.05 to 0.36	P = 2A, 47B S = 58, 2A-12, 1-60	1X
0.36 to 3.00	P = 2A, 47B S = 2ND, 58	10X

NOTE:

P = primary position
S = secondary position

Adjust fluorometer to zero on 0 microgram Be sample. Obtain fluorometer readings on each standard. Plot straight-line curve of amount of Be versus fluorometer readings.

(2) Curve No. 2 for 0 to 0.7 microgram Be:

Place millipore filters in 14 100-ml narrow-mouthed Erlenmeyer flasks. Transfer to the flasks, by means of a microburette, volumes of 0.10 microgram of Be/ml solution to give the following concentrations: 0, 0.05, 0.1, 0.2, 0.3, 0.5, and 0.7 microgram of Be. Treat these standards in the same way as the samples. Set slit at 1 X. Place filters 2A and 47B in the primary position and filters 2A-12, 58, and 1-60 in the secondary position. Adjust fluorometer to zero on the 0.0 microgram Be sample. Obtain fluorometer readings on standards. Set up a straight-line curve based on amount of Be versus fluorometer readings.

(3) Curve No. 3 for 0.7 to 5 micrograms of beryllium:

This curve is prepared in the same manner as curves 1 and 2 except that it is nonlinear. The slit is set at 10 X. The primary filters are 2A and 47B, and the secondary filters are 58 and 2ND. The curve is used to obtain an approximate beryllium concentration in samples containing large amounts of beryllium, so that an appropriate dilution factor can be made for subsequent assays using curve 2.

Instrumentation

A Turner fluorometer, Model No. 111, with a General Electric mercury lamp No. F4T4/BL was used. The major emission was at 360 mu. Wratten filters (2 by 2 inches) and numbering 2A, 47B, 2A-12, 58, 1-60 and 2NP were used with the fluorometer. The cuvettes were 12 by 75 mm round pyrex tubes. A Perkin-Elmer Model 303 atomic absorption spectrophotometer equipped with a nitrous oxide/acetylene burner and a digital concentration readout was used.

Reagents

(1) Morin* Indicator. Dissolve 0.160 grams of reagent grade Morin in 500 ml of absolute ethyl alcohol and dilute to 2000 ml with water. Store in a brown bottle at 15 to 20°C for maximum stability.

(2) Buffer Solution. Dissolve 156 grams of ACS grade sodium hydroxide (NaOH), 63 grams ACS grade citric acid, and 37 grams ACS grade boric acid in water and dilute to 1000 ml. Store in a polyethylene bottle.

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*Morin is available from:
Leonard Elion, 2 Concord Ave., Larchmont, New York and
Fluka Chemical Co., U.S.A. Distributor, International Chemical
and Nuclear Corp., 13332 E. Amar Road, City of Industry, California

(3) 5 Percent HEDTA/5 Percent EDTA. Dissolve 50 grams of hydroxyethylenediaminetriacetric acid (HEDTA), 50 grams of disodium ethylenediaminetetraacetric acid (EDTA), and 17.5 grams of sodium hydroxide in water and dilute to 1000 ml. Store in a polyethylene bottle.

(4) 1 Percent HEDTA/5 Percent EDTA. Dissolve 10 grams of HEDTA, 50 grams of EDTA and 3.5 grams of NaOH in water and dilute to 1000 ml.

(5) 0.02N-Tetrabutylammonium Hydroxide.* Convert an anion exchange column (2-XS, Dowex Resin) to the hydroxide form with 2N NaOH and rinse with water until neutral and chloride free. Follow the water rinse with dry methanol and dry benzene-methanol (10:1). Place 4 grams of tetrabutylammonium iodide and 2 grams of silver oxide into 45 ml of absolute methanol, chill to 0°C for 1 hour, centrifuge for 15 minutes at 1500 rpm, and discard the precipitate. Pour the supernatant liquid through the column prepared previously and elute with dry benzene. Dilute the collected effluent with dry benzene to 500 ml and standardize with ACS grade benzoic acid in dry pyridine to the bromcresol purple endpoint (light green).

(6) Beryllium Sulfate Solution. 1 Microgram of Be/ml. Dissolve 0.9820 gramsof $BeSO_4 \cdot 4H_2O$, purified, Fisher Scientific Co., in 10 ml of concentrated sulfuric acid. Heat if necessary. Cool. Transfer solution to 1000-ml volumetric flask containing 200 ml of distilled water. Dilute to volume. Mix. Take 10 ml of this solution and dilute to 500 ml, using 0.1 N sulfuric acid as diluent.

(7) Beryllium Sulfate Solution. 0.1 Microgram of Be/ml. Pipette 10 ml of 1 microgram of a 100-ml volumetric flask. Dilute to volume with 0.1 N sulfuric acid.

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*All organic solvents were dried over activated 5 Å molecular sieves.

(8) Phenol Red Solution. Dilute 0.1 gram of the sodium salt of phenolsulphonthalein, certified ACS grade to 250 ml with distilled water.

(9) Aluminum Nitrate Solution, 0.3 M. Dissolve 112.5 grams of $Al(NO_3)_3 \cdot 9H_2O$ ACS grade in 200 ml of distilled water and dilute to 1000 ml with distilled water.

(10) Ammonium Chloride Solution, 25 Percent. Add 250 grams of AR grade ammonium chloride to 750 ml of distilled water.

ATOMIC ABSORPTION SPECTROPHOTOMETRIC ANALYSIS (AA)

After July 1967 the fluorometric technique for trace beryllium determination was discontinued because the use of an AA equipped with a nitrous oxide/acetylene laminar flow burner significantly decreased the sample preparation and analysis time without greatly decreasing the sensitivity and accuracy of the analysis. Use of the AA technique (Reference 10) eliminated the requirement to completely decompose organic material, complex the transition metals or alkaline earths, and control the sample pH with a buffer. All samples were acidified with 36N sulfuric acid (2 ml) and 16N nitric acid (50 ml), evaporated on a hot plate until white fumes were evolved, and then diluted with water to 100 ml.

EXHAUST SPECIES ANALYSIS

The analytical results indicated that the quantity of N-methylpyrrolidineone soluble beryllium compounds formed during a successful firing were quite low despite the fact that elemental beryllium, beryllium hydroxide and beryllium chloride were all either soluble or could be converted to soluble forms by the absorbed hydrogen chloride. In addition, no free chlorine was found in the collected exhaust products.

The analytical methods used for the exhaust species trapped in the midget impingers containing aqueous sodium hydroxide and N-methylpyrrolidineone are presented.

Total Chloride (Reference 11)

An aliquot from an aqueous sodium hydroxide impinger solution was pipetted into a beaker and the pH adjusted to 2.9 to 3.0. Five drops of diphenyl carbazone (2 percent in ethanol)* and two drops of bromphenol blue (0.2 percent in ethanol) were added and the mixture titrated with 0.01N mercuric nitrate to a pink endpoint (persisted for 10 seconds). A reagent blank was subtracted from the analysis.

Ammonium Ion (Reference 12)

An aliquot from an aqueous sodium hydroxide impinger solution was adjusted to pH 12 with 1N sodium hydroxide and 1 ml of Nessler reagent added. After standing 10 minutes, the sample was compared to artificial color standards (Taylor), range 0 to 1 ug/ml ammonium ion.

Free Chlorine (Reference 12)

An aliquot from an aqueous sodium hydroxide impinger was acidified with 1N hydrochloric acid, and orthotolidine indicator was added. The color of the sample was compared to that of artificial color standards (Taylor), range 0.0 to 1.0 ug/ml chlorine.

Beryllium (Soluble/Beryllium Oxide)

The N-methylpyrrolidineone from an impinger was filtered through a 0.3 micron glass mat filter (Gelman), and both the filtrate and residue were analyzed for beryllium by the previously described techniques.

Hydrogen Chloride (Reference 13)

A portion of the filtrate (N-methylpyrrolidone) from the beryllium (soluble)/beryllium oxide separation was combined with dry pyridine* (50 ml), and titrated both potentiometrically and to the light green endpoint of bromcresol purple (0.5 percent in ethanol) with a dry benzene/methanol solution** of 0.02N tetrabutyl ammonium hydroxide. The burette used in the tiration was protected with an ascarite/anhydrone trap. A reagent blank was subtracted from the sample titration.

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*This indicator is stable for only 2 weeks in a brown bottle.

**Dried over activated 5 Å molecular sieves.

SECTION V
DATA ANALYSIS

The results of the analysis of Project ADOBE diffusion data are discussed. This data was collected and analyzed using meteorological and chemical techniques similar to those used in Project Sandstorm (Reference 5). But, whereas Project Sandstorm was limited to data collected under thermally unstable atmospheric conditions from small motors (15 to 18 pounds) and relatively short distances (2400 meters), Project ADOBE was designed to collect data under both thermally unstable and stable atmospheric conditions from large motors (100 to 4000 pounds) and extended distances (9600 meters).

DATA

A complete description of all meteorological and photographic data collected is contained in Volumes II and III of this report. Meteorological data collected during each test included wind speed, wind direction and temperature differential. The variance of the wind direction was calculated at various smoothing and sampling intervals. A brief description of this data is presented in Section I. Exposure data, also mentioned in Section I, was collected along arcs ranging from 300 to 9600 meters from the source. An example of the arcwise distribution of exposure from a test is shown in Figure 10. The exposure value chosen for the regression analysis was the peak value for the arc. Most of the arcwise distributions showed a well-defined single peak, but a few gave very erratic arcwise plots.

APPROACH AND GENERAL CONSIDERATIONS

The model used in the ADOBE regression equation was based on the work done under Project Sandstorm (Reference 5) and the Ocean Breeze and Dry Gulch Diffusion Programs (Reference 5 and 6) by the Air Force

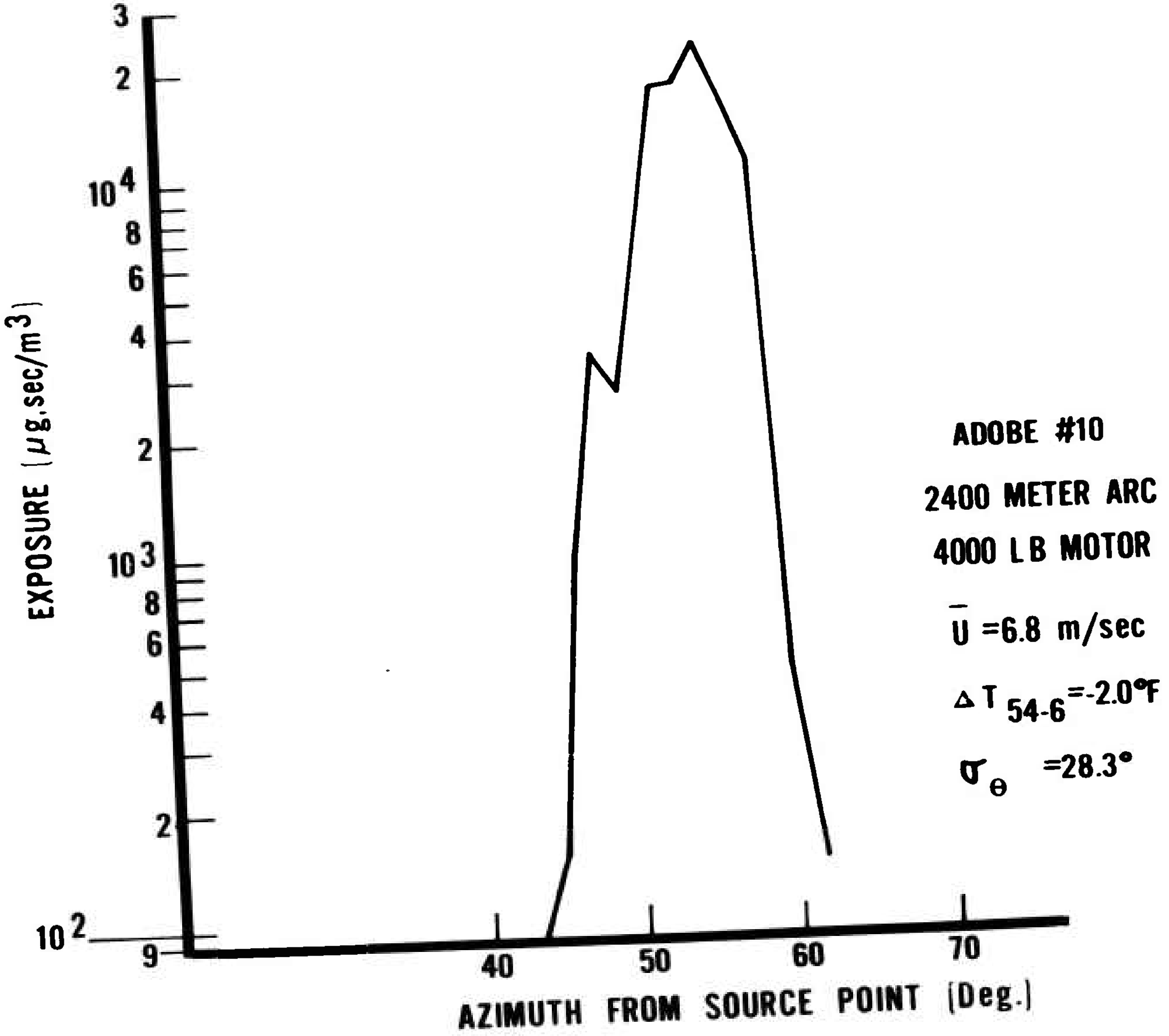

Figure 10. Arcwise Distribution of Exposure

Cambridge Research Laboratories (AFCRL). The assumption was made that the puff cloud from the exhaust of a rocket motor had a gaussian distribution of pollutant concentration, at least in the horizontal. The general form of the equation was:

$$Ep/Q = K X^{a} \left[\sigma_{\theta}{}^{2}\right]^{b} \bar{U}^{c} \left[\Delta T + \text{const}\right]^{d} \tag{1}$$

where

X = downwind distance in meters

Ep = peak exposure normalized for source strength, in units of seconds per cubic meter

Q = total amount of Troier material released

$\sigma_{\theta}{}^{2}$ = variance of wind direction fluctuations in units of degrees squared

$\bar{U}$ = mean wind speed in meters per second

ΔT + const = temperature differential in degrees F plus a constant large enough to always yield a positive number.

"K" and exponents "a" through "d" were values to be determined by the regression analysis. The equation was linearized using the logarithm of each term.

An initial regression analysis was accomplished with the data collected from the first 30 tests. The logarithmic form of the equation which provided the best fit of the data was:

$$\log (Ep/Q) = 5.55 - 1.02 \log X - 0.24 \log \sigma_{\theta}{}^{2} + 2.10 \log (\Delta T + 10) \tag{2}$$

$$= 0.77 \log (\bar{U})$$

where

σ_θ^2 = variance of the wind direction at 200 feet using 1-second smoothing intervals and a 128 second-sampling interval.

ΔT = temperature difference between 200 feet and 6 feet

$\overline{U}$ = the mean wind speed at 200 feet

Only two of the 30 tests had stable (positive) temperature differentials. Equation (2) had a multiple regression coefficient (r) of 0.66. If r^2 were taken to indicate the amount of explained data variation in this equation, only 44 percent would have been explained. Also, 74 percent of the data points fell within a factor of ±4 of the regression line.

Shown in Figure 11 are two plots of exposure versus downwind distance. Of the 64 tests conducted, test 14 was the only one with all five arcs of data. This test showed a straightforward decrease of exposure with distance. Test 30 was conducted under a strong temperature inversion. The curve showed an increase of exposure near 2400 meters. This type of anomaly appeared in several of the plots and could be attributed to a terrain effect. This test was also a good example of the complex nature of diffusion of a puff source and the problem inherent in a field experiment.

Phototheodolite data is presented in Volume III.

Two other diffusion data sources were used to develop the results of Project ADOBE. The first of these was collected at AFRPL during Project Sandstorm (Reference 5) using the same techniques as ADOBE. The second source of data came from the diffusion experiments conducted by the Aerojet-General Corporation under contracts with AFRPL and the Space and Missile Systems Organization (References 6 and 14). Much of

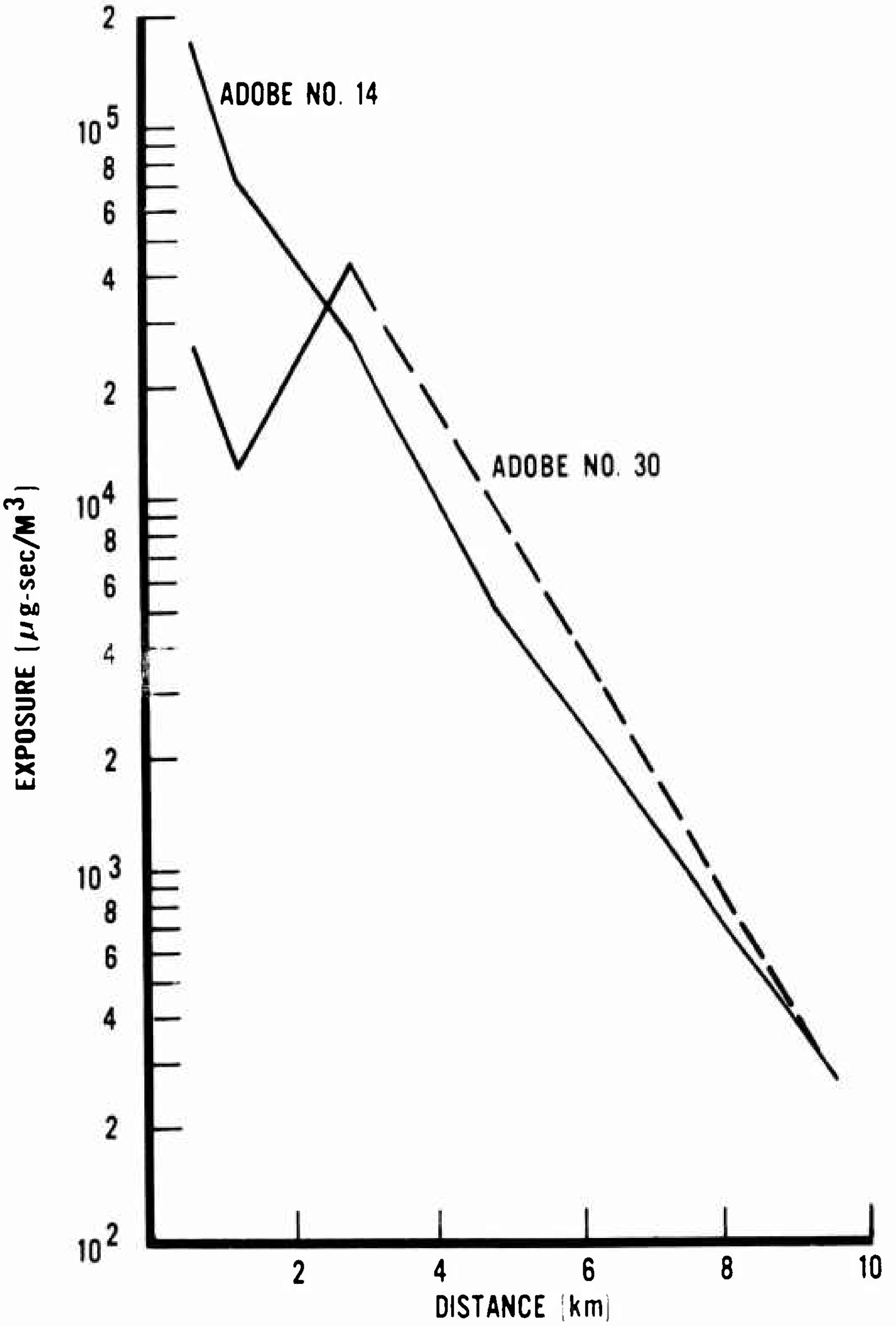

Figure 11. Downwind Distribution of Peak Exposure

this data was comparable to the ADOBE data but was primarily used in this report as an independent test of the final results. However, enough dissimilarity existed between the Lovelock, Nevada Test Site of Aerojet-General Corporation and AFRPL that extreme care should be taken in making comparisons.

Shown in Table VI is the range of data collected for each of the three sources of data.

TABLE VI. RANGE OF DATA

Parameter	Sandstorm		ADOBE		Aerojet	
	Min.	Max.	Min.	Max.	Min.	Max.
Distance (meters)	100	2400	600	9600	460	4763
12-Foot Wind Speed (M/sec)	2.3	12.6	2.1	14.9	1.0	12.1
Source (micrograms)	4.0×10^8	3.3×10^9	4.7×10^9	1.9×10^{11}	6.5×10^9	6.7×10^9
ΔT, 6-54 ft (degrees F)	-3.1	-0.3	-3.0	+7.7	0.1	11.2
Variance of Wind Direction (1, 128) at 12 feet (deg^2)	24.1	627.2	23.0	1053.0	1.0	6524.0

When all testing was complete, another analysis yielded a new equation. In this analysis, the model was changed to include Q, the source strength, as an independent variable. The regression coefficient was increased to 0.75 and 81 percent of the data were found within a factor of ±4 of the regression line. Some of the improvement derived from including Q as a variable was controversial. One bothersome fact concerning this new equation was the very slow decrease of exposure with increase in distance which made extrapolation nearly impossible. As a result, several other models were tried. Among these models were non-logarithmic, averaged values of peak exposure, categorization by source strength, categorization by distance, use of various combinations of the meteorological parameters, and others. A model which showed promise was the categorization by source strength; however, the available data was insufficient for further study. Although the analyses were unsuccessful, an insight into the problem was obtained, e.g., one analysis revealed an increase in the regression coefficient when the constant was not added to the ΔT term.

The ADOBE tests were separated into thermally stable and unstable data sets. The equation model was:

$$Ep/Q = K X^a \left[\sigma_\theta^2\right]^b \bar{U}^c \left|\Delta T\right|^d \tag{3}$$

The ΔT value has no additive constant and since the data was categorized by the sign of ΔT, no sign was needed in the equation. This model gave the best results of all the models used.

REGRESSION ANALYSIS AND RESULTS

In an attempt to develop an equation which would give operationally useful diffusion predictions, nearly 50 multiple regression passes were made to find the best set of parameters. The best results were obtained using the 6-foot to 54-foot temperature differential and the 12-foot wind values.

Equation 3 was linearized using common logarithms as follows:

$$\log (Ep/Q) = \log K + a \log X + b \log \left[\sigma_\theta^2 \, 1.128\right] + c \log \bar{U} + d \log \left|\Delta T\right| \tag{4}$$

The data and equation (4) were then evaluated using the 1965 version of BMD02R, stepwise regression program, developed by the University of California at Los Angeles (Reference 15). The results of the various analyses are listed in Table VII. The letters have the same meanings as stated in equation (4).

The best results as shown by Table VII were obtained by using the combined ADOBE-Sandstorm data for the thermally unstable case and the ADOBE data alone for the thermally stable case. In both sets of data, a few of the ADOBE exposure values were edited out.

The regression analysis actually yielded four equations instead of one. A new equation was developed each time a new variable was included. The equations for the unstable case were:

$$\log (Ep/Q) = 0.20 - 1.82 \log X \tag{5}$$

$$\log (Ep/Q) = 0.72 - 1.82 \log X - 0.49 \log \sigma_\theta^2 \tag{6}$$

$$\log (Ep/Q) = 0.70 - 1.82 \log X - 0.51 \log \sigma_\theta^2 + 0.23 \log (|\Delta T|) \tag{7}$$

$$\log (Ep/Q) = 0.98 - 1.82 \log X - 0.59 \log \sigma_\theta^2 + 0.27 \log (|\Delta T|) - 0.17 \log \overline{U} \tag{8}$$

The correlation between the logarithms of the five variables is shown in Table VIII.

TABLE VII. SUMMARY OF RESULTS USING EQUATION (4)

Data Set	Multiple Regression Coefficient, r	r^2	log K	a	b	c	d
ADOBE, $\Delta T<0$	0.63	0.40	-1.01	-1.19	-0.66	-0.38	0.09
Sandstorm	0.83	0.69	0.69	-1.62	-0.64	-0.27	0.36
ADOBE, $\Delta T<0$, plus Sandstorm	0.84	0.71	0.83	-1.78	-0.57	-0.17	0.21
ADOBE, $\Delta T<0$, plus Sandstorm Edited	0.88*	0.77	0.98	-1.82	-0.59	-0.17	0.27
ADOBE, $\Delta T>0$	0.70	0.49	-2.87	-1.18	0.75	0.57	-0.07
Aerojet	0.65	0.43	-0.59	-1.23	-0.19	-0.82	0.04
ADOBE, $\Delta T>0$, plus Aerojet	0.66	0.44	-1.24	-1.35	0.14	0.04	0.13
ADOBE, $\Delta T>0$ Edited	0.73*	0.53	-2.64	-1.28	0.70	0.91	-0.06

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*Final equations

TABLE VIII. CORRELATION COEFFICIENTS BETWEEN LOGARITHMS OF VARIABLES IN EQUATIONS (5), (6), (7) AND (8)

Parameter	$\overline{U}$	σ_θ^2	$\lvert\Delta T\rvert$	Ep/Q
X	0.02	-0.01	-0.02	-0.86
$\overline{U}$		-0.84	0.20	0.13
σ_θ^2			0.13	-0.16
T				0.04

The corresponding equations obtained for the stable case were:

$$\log (Ep/Q) = -1.06 - 1.35 \log X \qquad (9)$$

$$\log (Ep/Q) = -2.30 - 1.25 \log X + 0.76 \log \sigma_\theta^2 \qquad (10)$$

$$\log (Ep/Q) = -2.74 - 1.27 \log X + 0.72 \log \sigma_\theta^2 + 0.98 \log \overline{U} \qquad (11)$$

$$\log (Ep/Q) = -2.64 - 1.28 \log X + 0.70 \log \sigma_\theta^2 + 0.19 \log \overline{U} - 0.06 \log (\lvert\Delta T\rvert) \qquad (12)$$

The correlation matrix obtained for the stable equations was as shown in Table IX.

TABLE IX. CORRELATION COEFFICIENTS BETWEEN LOGARITHMS OF VARIABLES IN EQUATIONS (9), (10), (11) AND (12)

Parameter	$\overline{U}$	σ_θ^2	$\lvert\Delta T\rvert$	Ep/Q
X	0.04	-0.14	-0.18	-0.64
$\overline{U}$		0.10	-0.64	0.17
σ_θ^2			-0.39	0.40
ΔT				-0.12

Just how the deletion of parameters affects the accuracy of the estimation is shown in Table X. Also, examination of Tables VIII, IX and X indicates possible simplification.

As shown in Table VIII for the unstable equations, (5) through (8), the only parameter well correlated with Ep/Q was distance. Shown in Table VIII is the fact that no improvement was realized by including ΔT and $\overline{U}$ as parameters. Further examination indicates that the variance term gave little improvement. Thus equation (5) could be used with little loss of accuracy. This observation compares well with the results of Project Sandstorm (Reference 5).

The same type of examination of the stable equations (9) through (12) indicated different results. Both distance and variance were well correlated with Ep/Q. Considerable improvement was realized as shown in Table X when the variance term was included.

TABLE X. EFFECT OF PARAMETER DELETION

Equation No.	r	r^2	Total Decrease in r^2	Percentage Within ±2 Factor	Percentage Within ±4 Factor	Percentage Over Prediction Factor 4
8	0.88	0.77		42	78	5
7	0.88	0.77	0.00	41	76	5
6	0.87	0.76	0.01	40	75	5
5	0.86	0.74	0.03	37	72	7
12	0.73	0.54		42	83	3
11	0.73	0.54	0.00	47	86	0
10	0.72	0.51	0.03	39	86	0
9	0.64	0.41	0.13	53	83	3

The last column of numbers in Table X was quite important operationally because the numbers showed the percentage of times that the predicted value was less than one-fourth the observed value. For example, equation (8) gave 78 percent of the values within a factor of ±4. Of the remaining 22 percent of the values, only 5 percent was under the predictions.

An important step in demonstrating the accuracy of the equations was the comparison with independent data. This data was obtained from tests conducted by the Aerojet General Corporation at their Lovelock, Nevada, test facility (References 6 and 14). Several cases were tested, two of which are shown in Figures 12 and 13. The terrain at Lovelock was similar to that at AFRPL. Good agreement with the predictions was shown in Figures 12 and 13. Many tests conducted by Aerojet General Corporation showed similar agreement; however, in some cases, observed exposure increased with distance. This could be caused by terrain influences or changes in stability during the time that the exhaust cloud was definable.

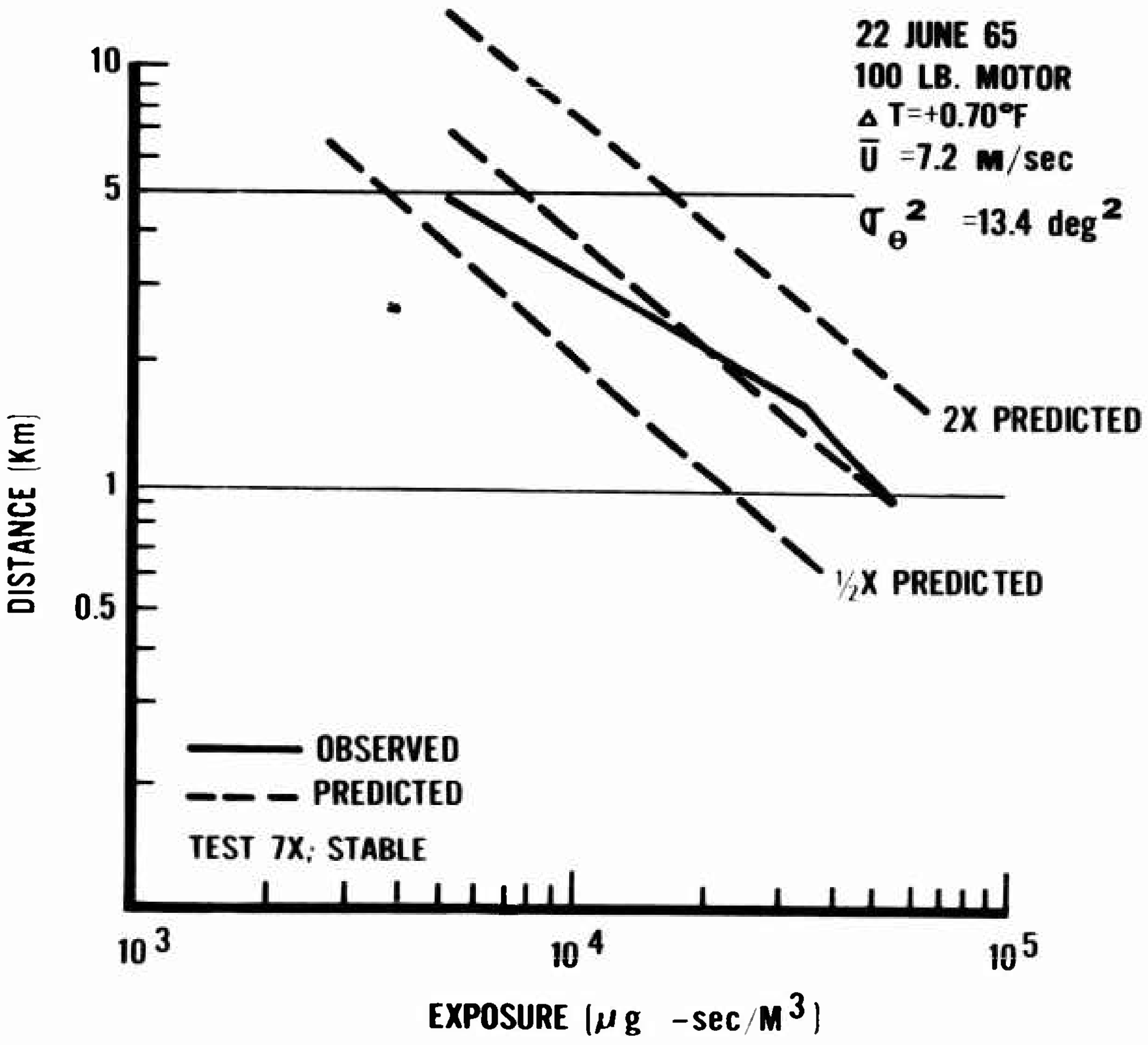


Figure 12. Exposure Verification With Aerojet-General Test 7X

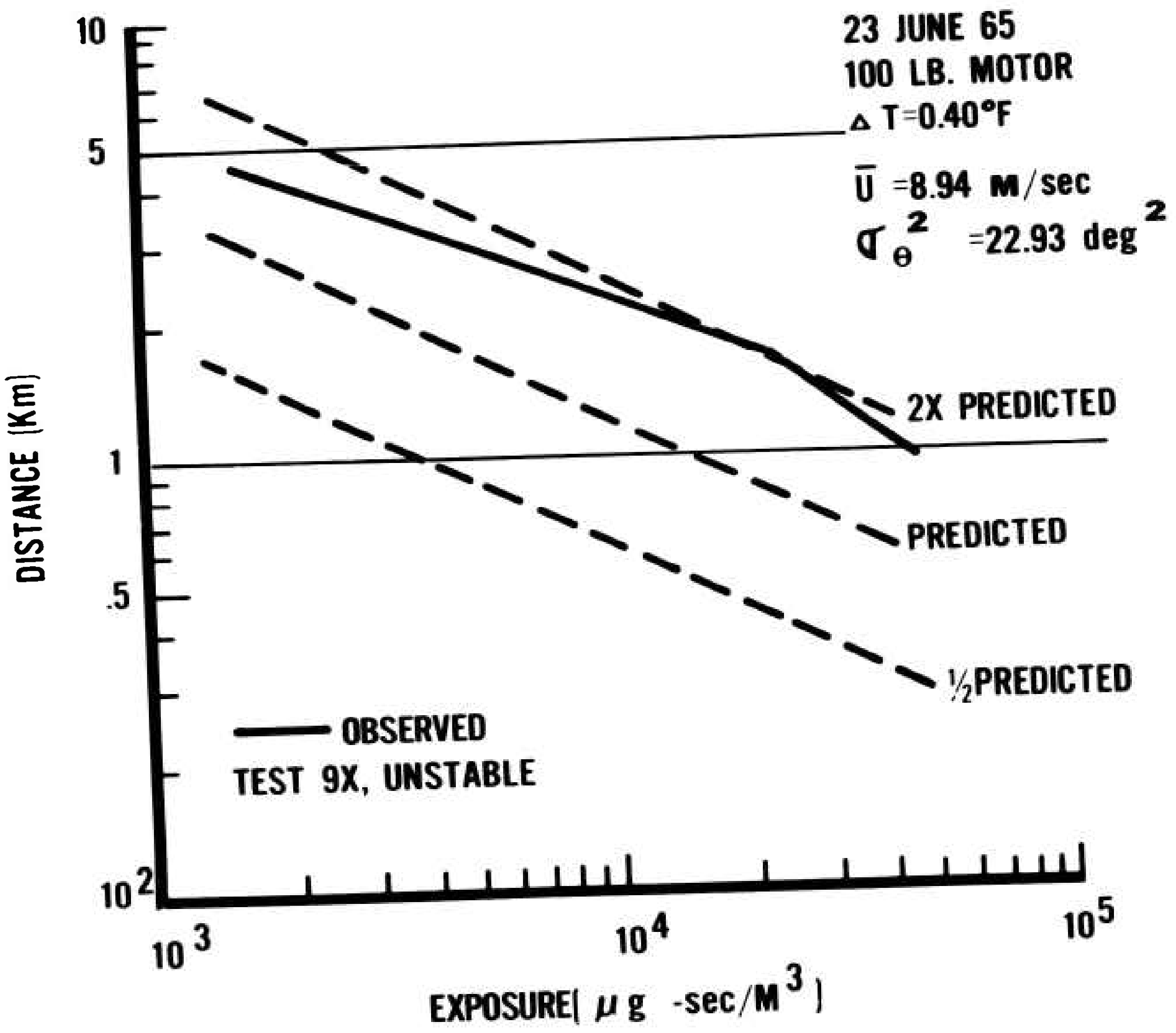


Figure 13. Exposure Verification With Aerojet-General Test 9X

Two other equations were developed after those that were considered the "final results." The previous equations used Ep/Q as the dependent variable; however, the primary use of the equations was to predict distances. When the regression coefficient departed significantly from unity, the validity of transposing equations became questionable. To check this, the same data sets used to develop equations (8) and (12) were reanalyzed using distance as the dependent variable. The equations developed in full form are:

when $\Delta T < 0$,

$$\log X = 1.04 - 0.42 \log (Ep/Q) - 0.22 \log \sigma_\theta^2 - 0.02 \log \bar{U} + 0.09 \log (|\Delta T|) \tag{13}$$

and, if $\Delta T > 0$,

$$\log X = 1.60 - 0.33 \log (Ep/Q) + 0.05 \log \sigma_\theta^2 - 0.37 \log (|\Delta T|) \tag{14}$$

Statistics for equations (13)and (14) are found in Table XI.

TABLE XI. REGRESSION STATISTICS OF EQUATIONS WITH X AS DEPENDENT VARIABLE

Equation No.	r	r^2	Percentage Within ±2 Factor	Percentage Within ±4 Factor	Percentage Under Predicted Factor 4
13	0.87	0.76	76	95	1
14	0.69	0.48	57	92	8

The percentage values in Table XI were the logarithms of the actual numbers. The antilogarithms were used in Table X. A comparison of equations (8) and (12) with equations (13) and (14) are shown in Figure 14. The correlation matrices were identical to those listed in Tables VIII and IX, as expected. The old equations simplified for (13) and (14) as shown previously, were presented as:

$$\log X = 0.69 - 0.40 \log (Ep/Q) \qquad (15)$$

$$\log X = 1.71 - 0.32 \log (Ep/Q) - 0.39 \log (|\Delta T|) \qquad (16)$$

The following nonlogarithmic forms of the ADOBE equations were programmed on-line in the AFRPL IBM 1800 computer to provide real-time analyses of diffusion from rocket propellant releases. These equations are for the 95 percent confidence level.

For $\Delta T<0$

$$Ep = 3.05\mathrm{x}10^{9}\ Q(0.30D)^{-1.78}\ (0.51\bar{U})^{-0.17}\ (\sigma_\theta{}^2)^{-0.57}\ (|\Delta T|)^{+0.21} \qquad (17)$$

$$D = 6.08\mathrm{x}10^{5}\ \bar{U}^{-0.02}\ (\sigma_\theta{}^2)^{-0.22}\ (\Delta T)^{+0.09}\ Ep^{-0.42}\ Q^{+0.42} \qquad (18)$$

$$Q = 3.28\mathrm{x}10^{-10}\ Ep(0.30D)^{+1.78}\ (0.51\bar{U})^{0.17}\ (\sigma_\theta{}^2)^{+0.57}(|\Delta T|)^{-0.21} \qquad (19)$$

For $\Delta T>0$

$$Ep = 6.19\mathrm{x}10^{5}\ Q(0.30D)^{-1.18}\ (1.51\bar{U})^{0.57}\ (\sigma_\theta{}^2)^{0.75}\ (|\Delta T|)^{-0.07} \qquad (20)$$

$$D = 3.76\mathrm{x}10^{5}\ (\sigma_\theta{}^2)^{+0.05}\ (\Delta T)^{-0.37}\ Ep^{-0.33}\ Q^{+0.33} \qquad (21)$$

$$Q = 1.62\mathrm{x}10^{-6}\ Ep\,(0.30D)^{+1.18}\ (0.51\bar{U})^{-0.57}\ (\sigma_\theta{}^2)^{-0.75}\ (|\Delta T|)^{0.07} \qquad (22)$$

When $\Delta T = 0$, change to +0.1 or -0.1

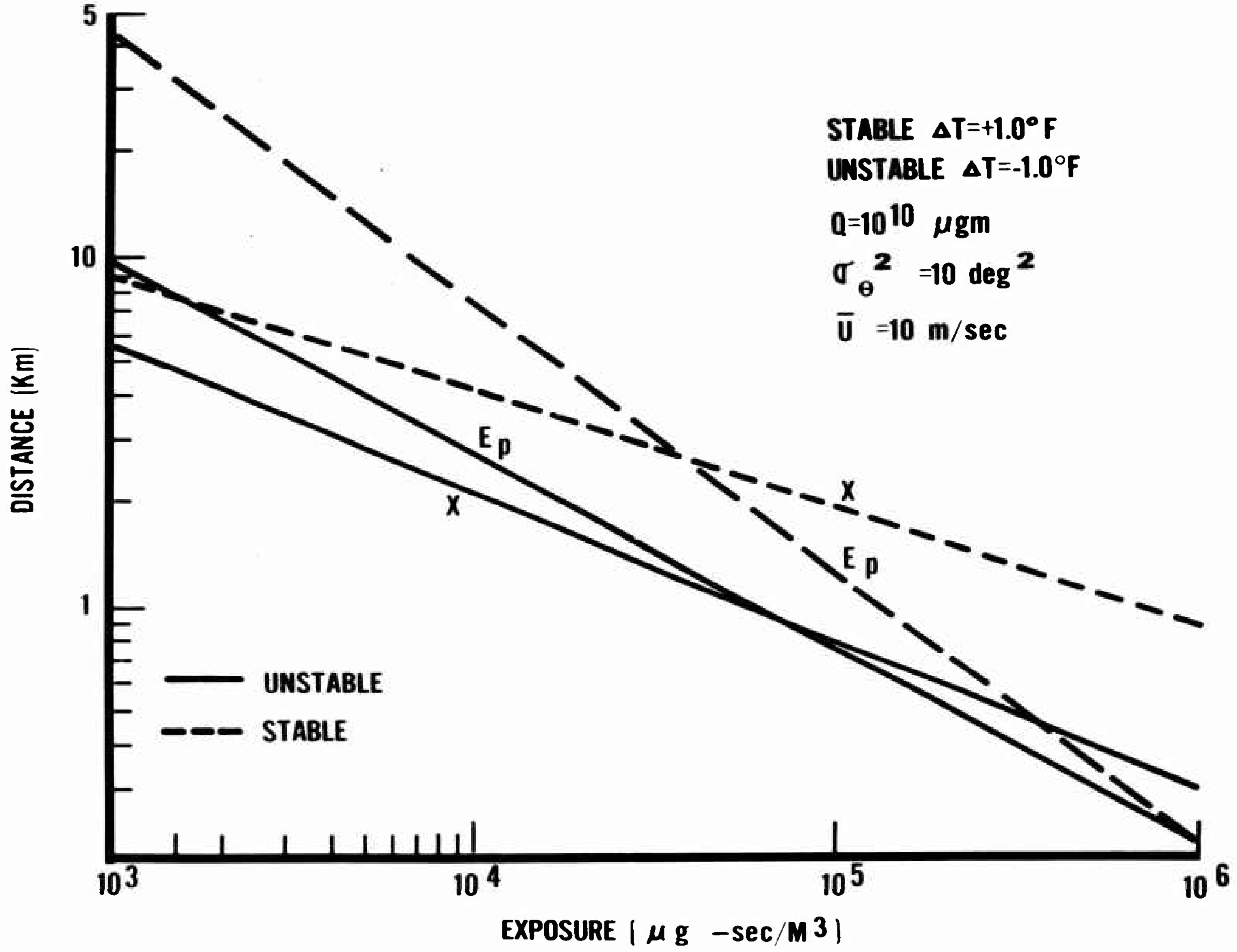


Figure 14. Comparison of Equations (8), (12), (13) and (14)

where

Ep = peak exposure [μg - sec/m^3]

D = distance downwind (feet)

Q = quantity of material released (pounds)

$\bar{U}$ = average wind speed (knots)

ΔT = 6 to 54 feet temperature differential (^{o}F;

A comparison was made between the Sandstorm equation and the ADOBE equations, (5) and (9), as shown in Figure 15. The slight difference can probably be accounted for by the larger motors used in ADOBE which increased the near field exposures. The added cloud rise accounted for the decrease in exposures at 10 kilometers.

DISCUSSION

The results of Project ADOBE provided AFRPL with the high-confidence answers needed for operational decisions. The statistics of the equations were quite satisfactory, especially for the thermally unstable case, the normal situation for testing. The equations predict best at distances near 2400 meters. The poorest results from the equations were found near the source.

Drawing physical meaning from an empirical equation was both dangerous and tempting. Yielding to the temptation, the following observations and points are offered for consideration:

The first point of concern was the addition of a constant to the ΔT term. At first glance, it appeared to have no effect upon the equation, which would be true if the source were nonbuoyant. But in the buoyant case, this

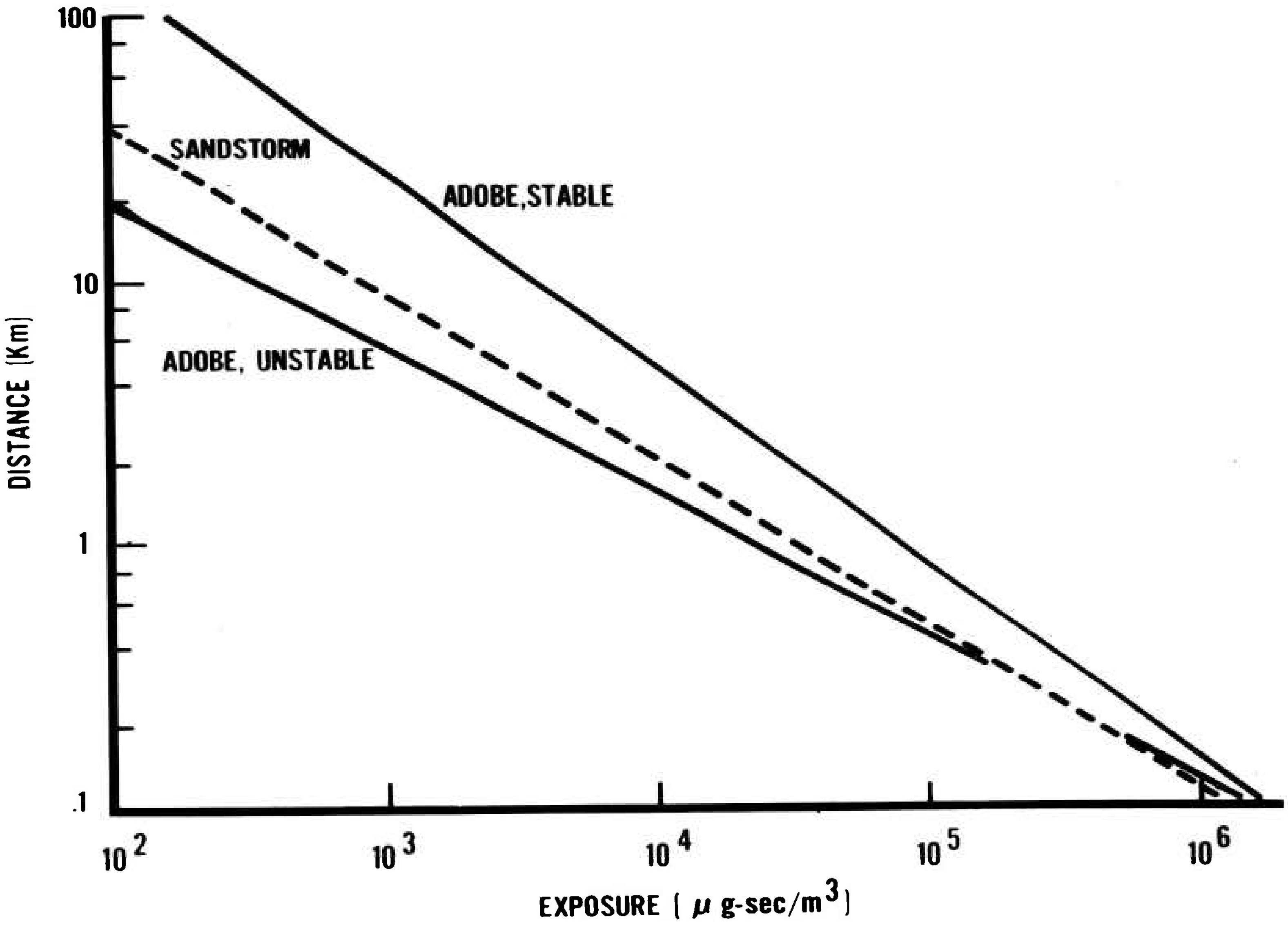


Figure 15. Comparison of ADOBE and Sandstorm Diffusion Equations

constant masked the true physical process. In considering the stable cases, the effect of stability on the cloud at a given height above the ground was to inhibit its vertical dispersion. Since ground level exposure was the objective of this work, increased stability was found to actually decrease ground level exposures by decreasing the vertical dispersion. In effect, the stable lapse rate acted as a buffer between the ground and the cloud. When (ΔT + const) was used, the opposite result was obtained, i. e., ground level exposure increased with increasing stability. (This assumed, of course, that the buoyant cloud did not penetrate the inversion.)

Another point was the correlation between $\bar{U}$ and σ_θ^2. In considering the thermally unstable case, the correlation between $\bar{U}$ and σ_θ^2 was high, -0.84. Thus, the two variables were strictly not independent. The regression statistics showed little improvement by including $\bar{U}$. In the stable case, σ_θ^2 and $\bar{U}$ were not well correlated with each other though σ_θ^2 was an important parameter. The apparent correlation between $\bar{U}$ and Ep/Q in the unstable case was probably due to the high correlation between $\bar{U}$ and σ_θ^2. Wind speed, while not important for calculations under unstable conditions, was important for the correlation between σ_θ^2 and $\bar{U}$.

The sign of σ_θ^2 was also considered. This term represented the lateral dispersion of the cloud. When $\Delta T < 0$, this term contributed to decreased ground level exposures as it became larger. However, under stable conditions, the increased dispersion with a large σ_θ^2 helped to spread the material downward and increased the exposures near the surface while decreasing the concentration at the cloud level.

The results of the regression analysis logically describe the observations if one remembers that the source was initially elevated. Indeed, visual observation of static rocket firings substantiated the predictions. One of the complexities of the problem was that the parameters used as variables were not always strictly independent. Considering the total accuracy of the equations and the fact that they explain what was observed, they are operationally useful expressions.

Case Study

An analysis of ADOBE test 14 was used as a case study. This test was chosen because all of the required data was available and because it contained no anomalies. Test 14 was conducted on 8 June 1965 at 1050 PST. The total weight of the propellant in the solid motor was near 850 pounds and contained 84.97 pounds of beryllium (3.854 x 10 micrograms). The duration of the firing was 27 seconds. Weather conditions were near perfect with clear skies and a visibility of 7 miles. The temperature was 63°F and the relative humidity was 46 percent. The following data was collected at the meteorological tower:

Height (feet)	Wind Direction and Speed (mi/sec)	Variance of Wind Azimuth	Temperature Difference From 6 Feet
12	252/10.7	50.4 deg^2	
50	268/13.0	64.8 deg^2	-2.6°F
100	XXX/13.4	Missing	-3.5°F
200	267/14.3	30.53	-4.0°F

All five sampling arcs were in operation for this test. Table XII indicates the distribution of samplers.

In Figures 16 and 16a the arcwise distribution of exposure was reduced to show only that portion of the data that defined the peak.

Exposures were determined by dividing the total mass of material collected on each sampler by the average flow rate through the sampler.

TABLE XII. THE SAMPLING ARCS AND SAMPLER LOCATION FOR TEST 14

Arc No.	Distance from Source (meters)	Azimuth from Source (degrees)	Spacing (degrees)	No. of Samples
6	600	12 - 82	2.0	36
12	1200	6 - 91.5	1.5	58
24	2400	6 - 102	1.5	65
48	4800	6 - 102	1.0	97
96	9600	21 - 102	1.0	82
				338

Photographs of the exhaust cloud are presented in Figure 17. These photographs show the cloud from firing time plus 3 seconds to firing time plus 127 seconds. The growth of the cloud, buoyant rise and dispersion can be observed. In the frame of Figure 17d, the cloud was about 1000 feet long, 650 feet in depth and was 220 feet from the ground. The cloud was being transported by the wind at about 1/4 mile per minute; thus, the initial momentum and horizontal dispersion must have accounted for about 600 feet in 127 seconds. The vertical growth of the cloud is shown in Figure 18. The best estimate for heat energy of the burning propellant was 1.43 kcal/gm.

The horizontal dispersion of the cloud, as indicated by the cloud-tracking data, is shown in Figure 19. At about 100 seconds, the cloud appears to rotate. This phenomenon, which appeared in several of the tests, makes the use of the photo-tracking data difficult. The cloud followed the 12-foot wind direction quite well and the peak exposures were consistent. The photographic data ended at 231 seconds although the cloud had not yet reached the 4800-meter arc. The mean wind was reconstructed from the 64-second averages of data taken from the meteorological tower; thus, there were probably time and space differences in the wind that the cloud actually experienced.

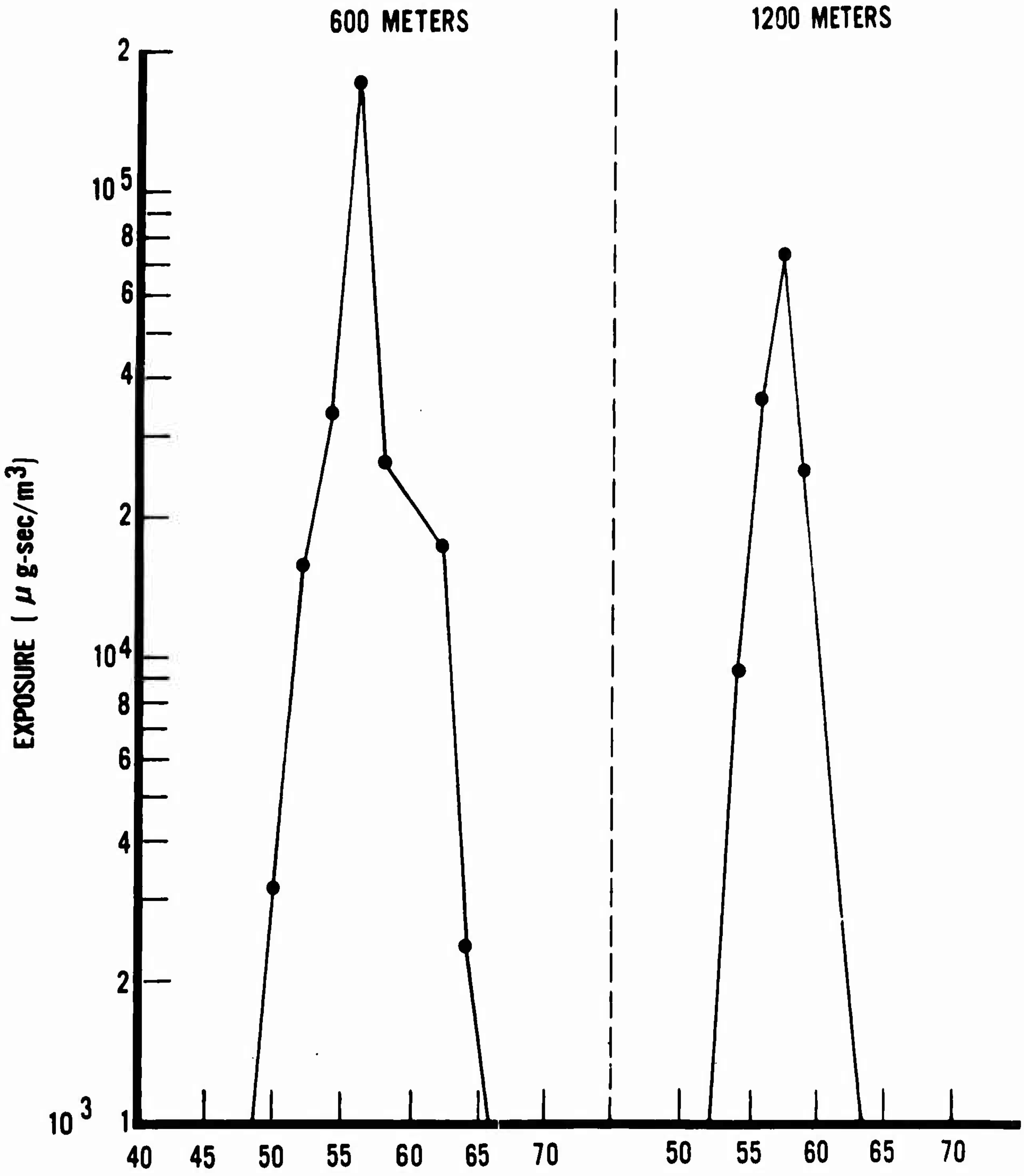


Figure 16. Azimuth from Source Point

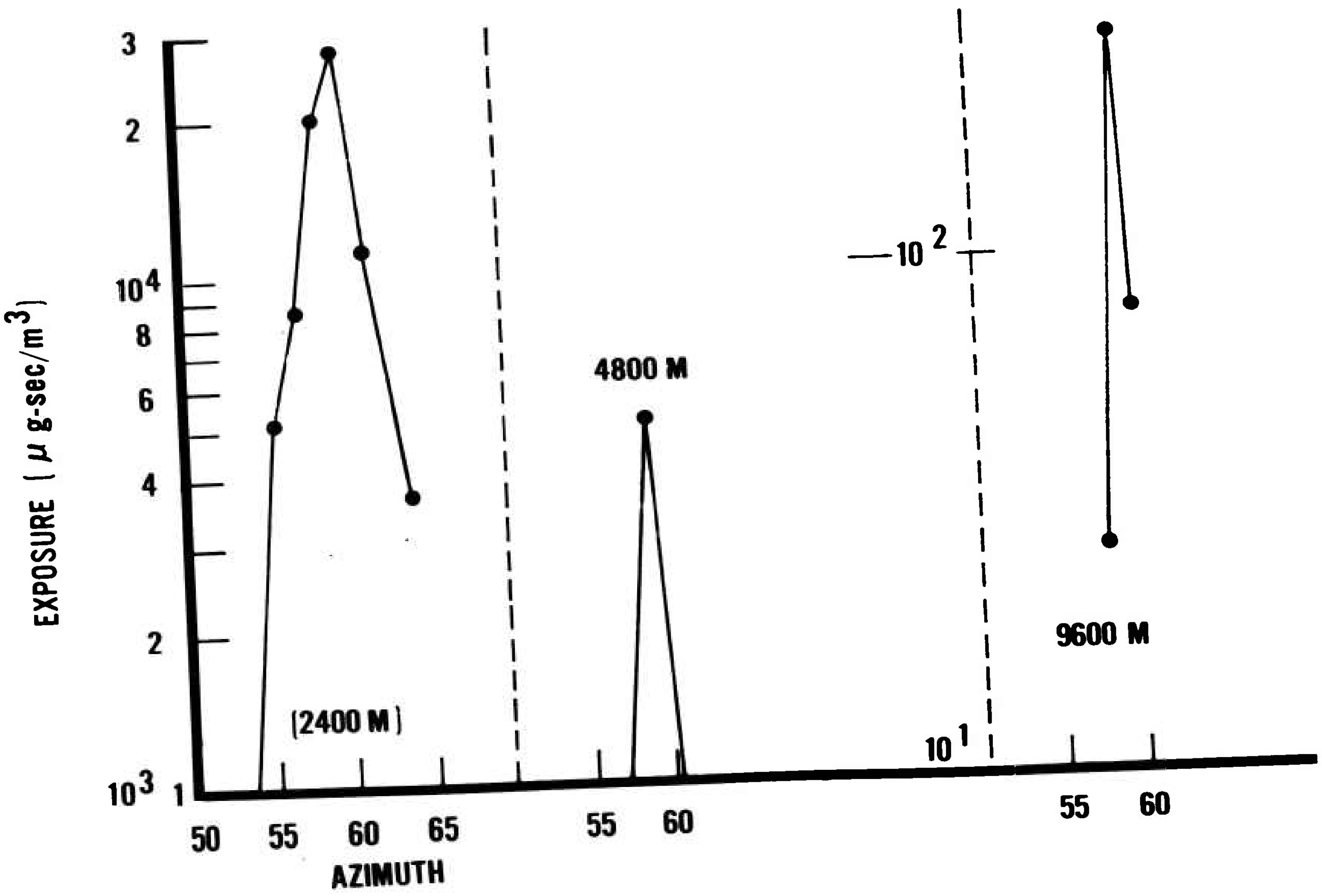
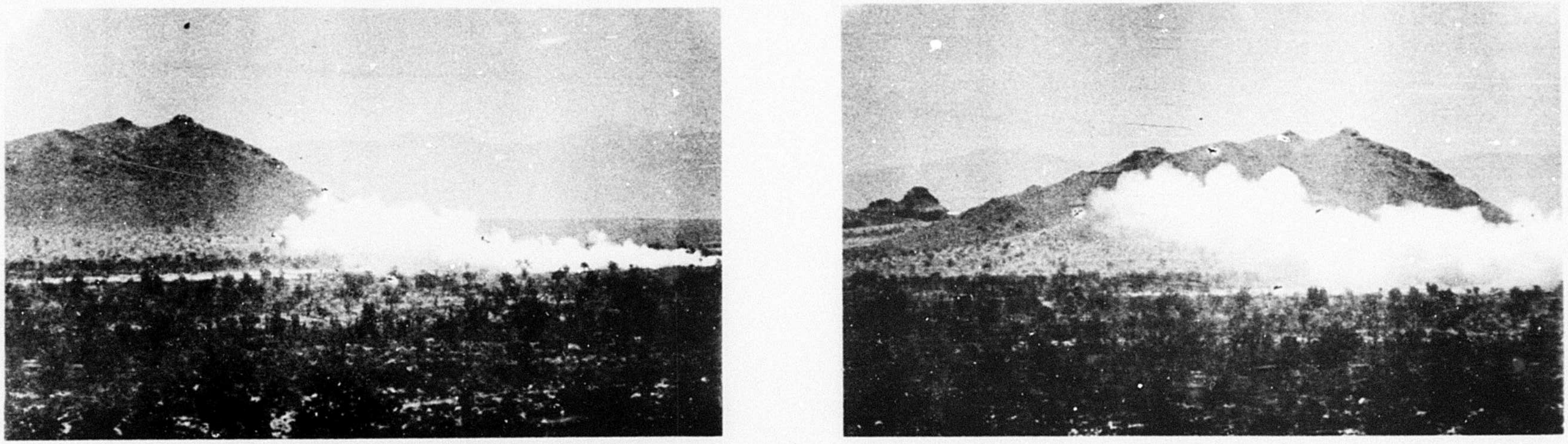
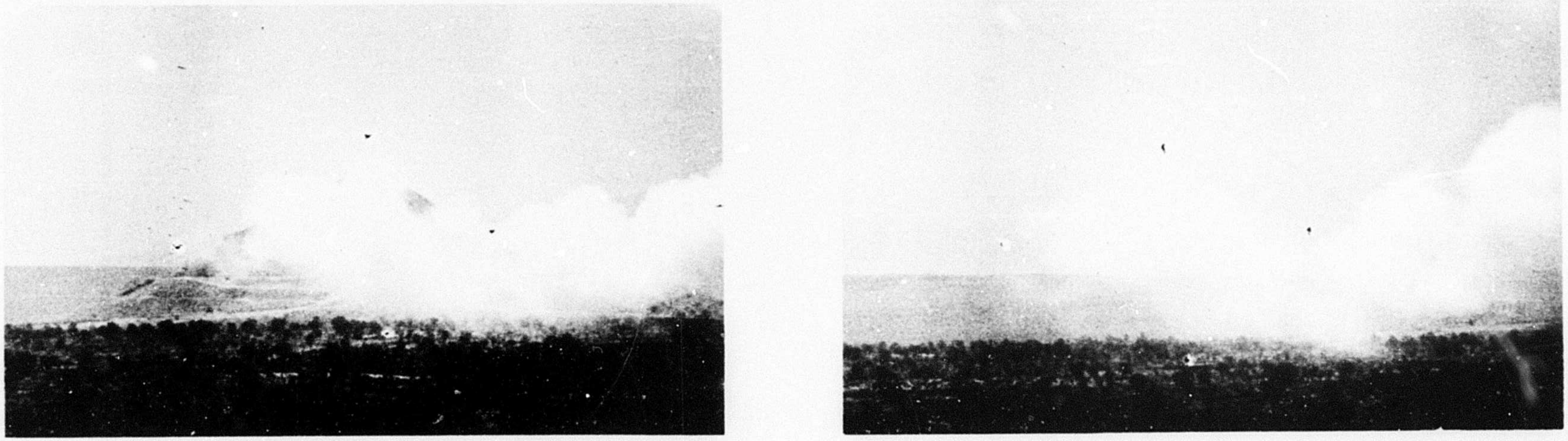


Figure 16a. Peak Data-Arcwise Distribution



a. Time = 3 sec D = 218 ft

b. Time = 37 sec D = 1938 ft



c. Time = 83 sec D = 4409 ft

d. Time = 127 sec D = 6532 ft

Figure 17. Exhaust Cloud Photographs, ADOBE Test 14

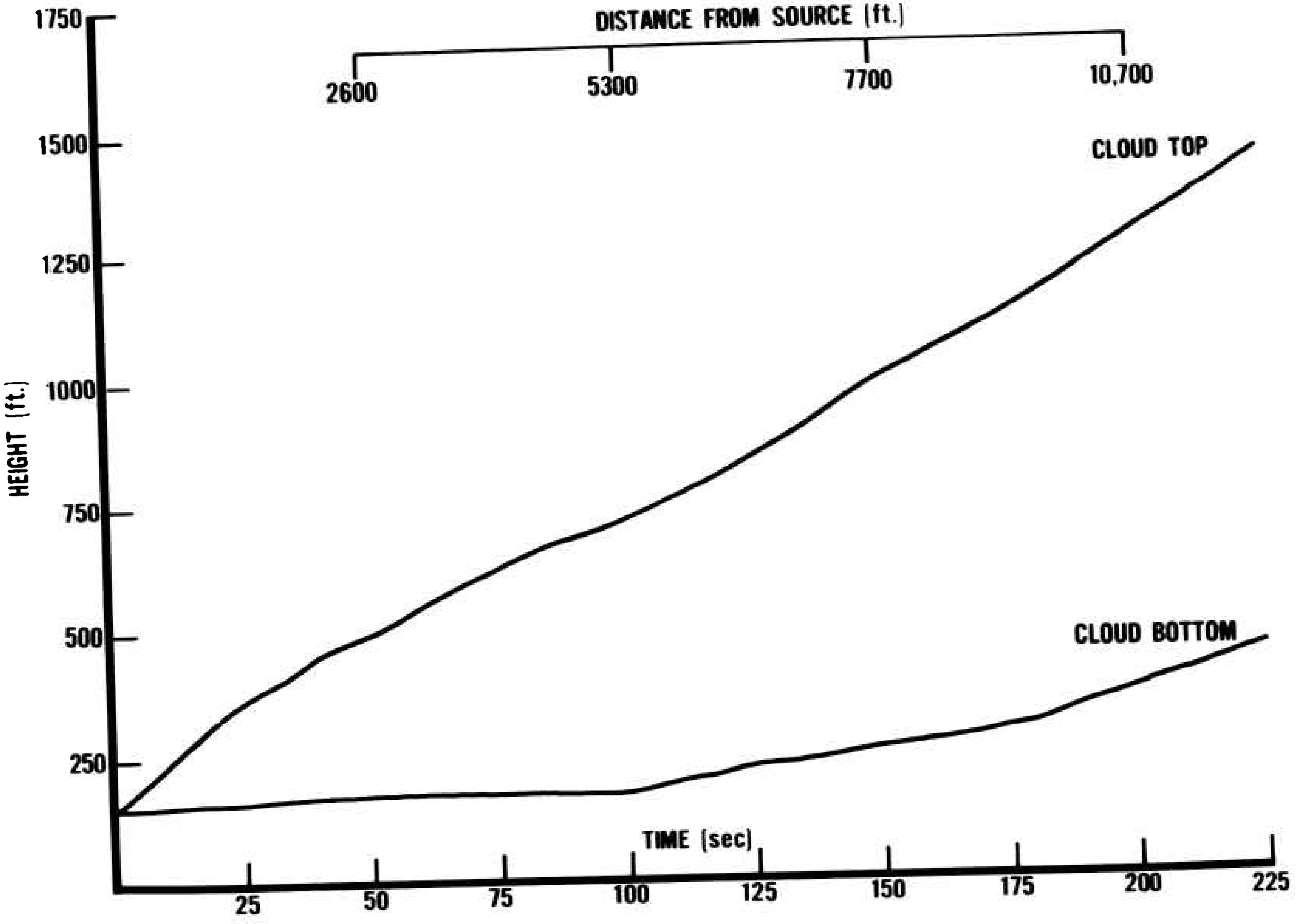


Figure 18. Vertical Growth of a Rocket Exhaust Cloud

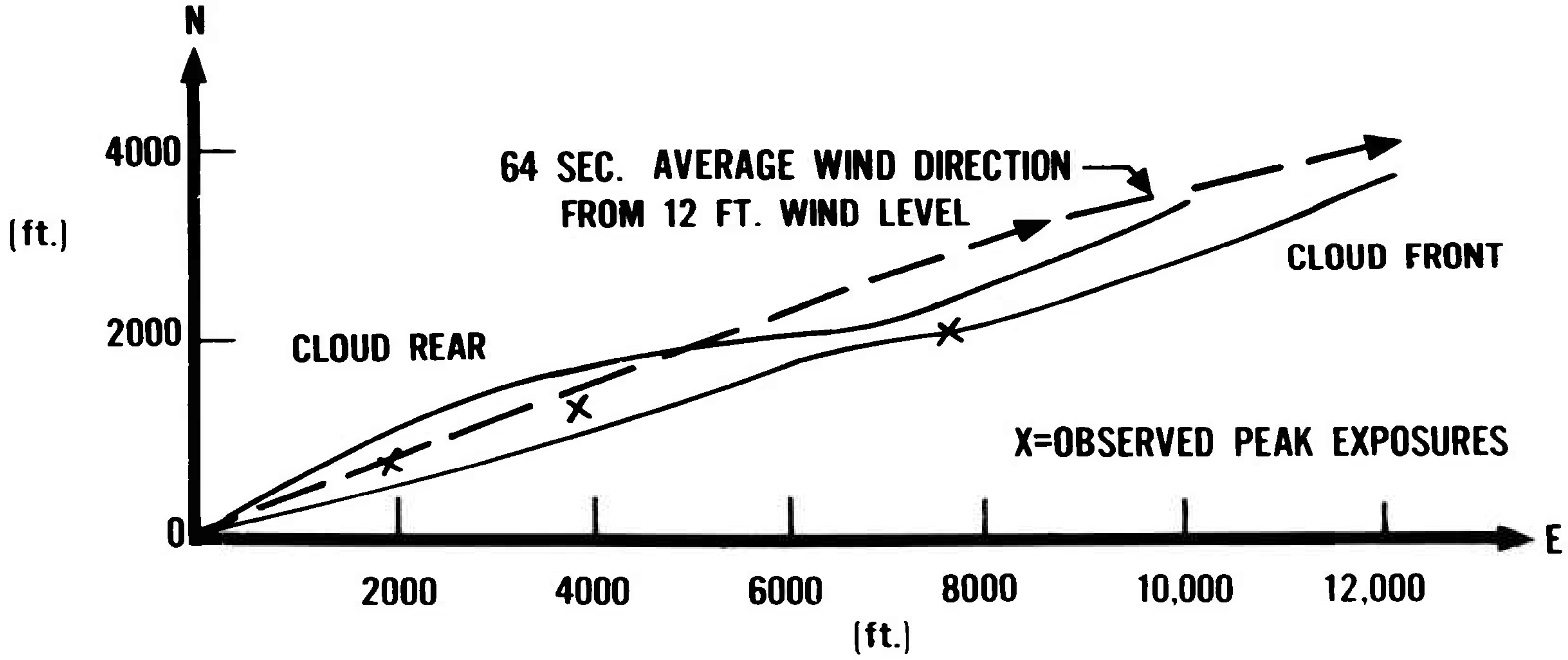


Figure 19. Horizontal Dispersion of the Exhaust Cloud

Rawinsonde data was available from Edwards AFB. However, the data was 7 hours earlier than the firing and thus is not presented here. At the time of the rawinsonde observation, the normal radiation inversion dominated the low level data. This inversion had dissipated well before the test.

The exhaust cloud behaved in a normal manner and the actual peak exposures were compared with predicted exposures in Figure 20. The agreement was very good.

The curves shown in Figure 20 were in very close agreement until 9600 meters. Even there, the prediction was higher than the observed data, or on the safe side. Further, the prediction was a reasonable value, well below the prescribed limits for this material. Keep in mind that data was unavailable between the arcs. If the cloud had been looping, the exposure value at 2000 meters, for example, could have been much higher than indicated.

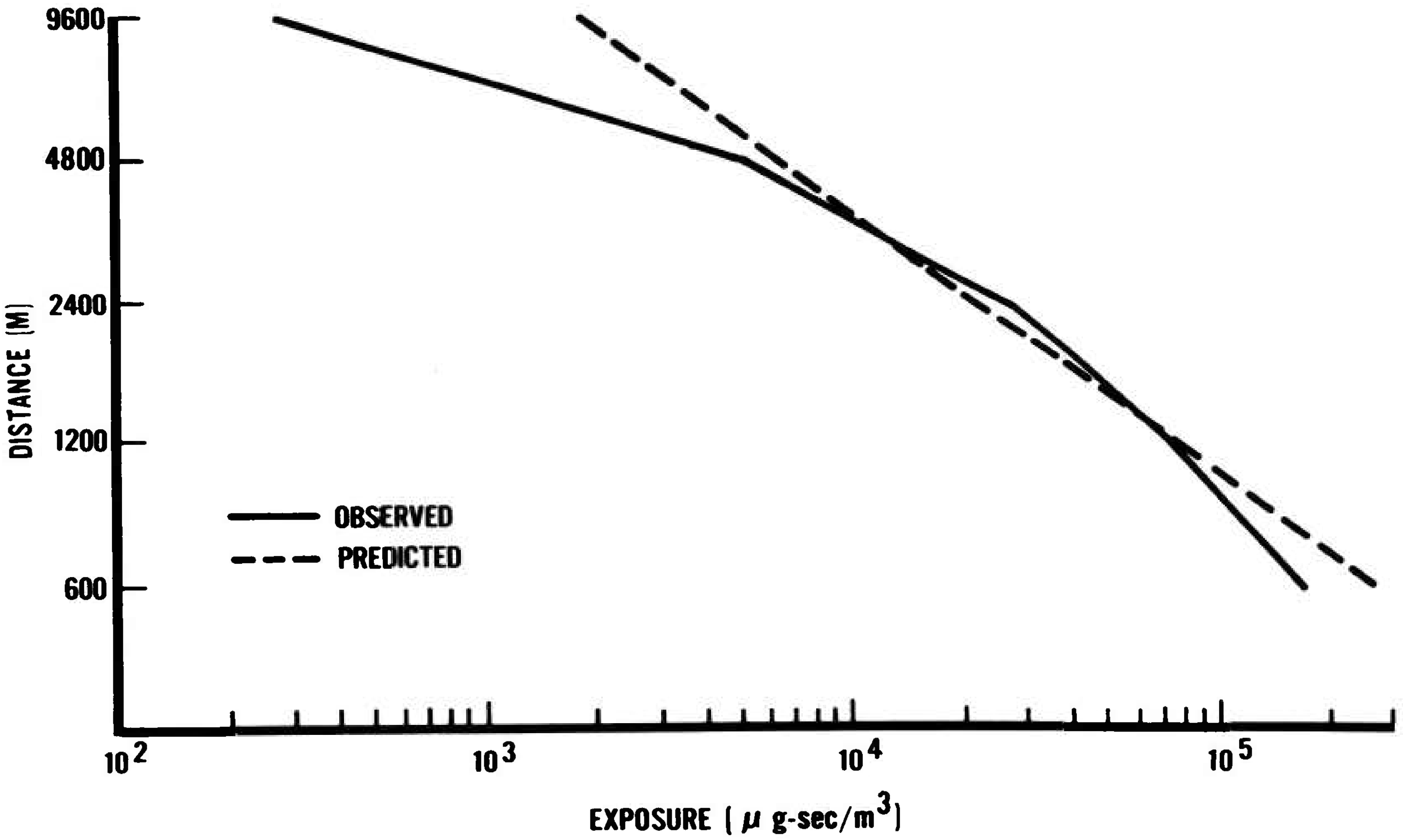


Figure 20. Predicted versus Observed Peak Exposures, ADOBE Test 14

SECTION VI

BIOENVIRONMENTAL ENGINEERING PROGRAM

The firing of beryllium propellant exhaust product into the atmosphere required an extensive environmental monitoring program which was essentially an extension of monitoring programs carried out during Project Sandstorm. The program involved quantitative measurement of airborne concentrations of beryllium generated within the working environment and within the sparsely populated communities surrounding the Air Force Rocket Propulsion Laboratory. In addition, the effect of the firing program on ground surfaces was analyzed and measurements of particulate resuspension were made. A medical surveillance program was carried out on individuals involved in any phase of the operation where quantities of beryllium could cause potential overexposure. The environmental monitoring program was conceived and initially carried out under the direction of Capt O. H. Kittilstad and Capt C. V. Eggert, Bioenvironmental Engineers of the USAF Biomedical Sciences Corps.

TOXICITY

The toxicity of beryllium compounds has been recognized since the 1940's. The first beryllium control standards within the U. S. were promulgated by the Beryllium Medical Advisory Committee to the Atomic Energy Commission in 1948 in response to the hundreds of beryllium disease cases which developed within industry. The use of control standards and exhaust control measures reversed the course of beryllium disease. Approximately 12 cases of chronic beryllium disease were contracted since engineering control measures were instituted, but these cases were effectively controlled by steroid medication with no permanently disabling effects.

The two areas of concern in beryllium-induced illness are the dermal and respiratory systems with the types of beryllium disease classified as acute or chronic. The term berylliosis was used by Fabroni (Reference 16) in 1935 to describe the effects of acute beryllium poisoning in laboratory animals, although this term was used indiscriminately to describe both acute and chronic cases of pulmonary disease. Berylliosis is currently defined within the literature as chronic disease which primarily is manifested by abnormal lung tissue changes with variable secondary systemic alterations. Acute dermal effects of beryllium disease can be classified into a variety of dermatological effects caused by soluble compounds of beryllium. Historically, these reactions were associated with industrial processing of soluble beryllium fluoride salts with a few reported cases caused by sulfate compounds.

An allergic reaction of skin surfaces in contact with fumes, dusts or mists of fluoride compounds can cause an intense inflammatory reaction within several weeks after exposure. This reaction appears to be allergenic, and the demonstrated intolerance indicates removal of the worker from the exposure environment.

A similar inflammatory reaction of exposed skin surfaces can also be caused after prolonged contact with soluble fluoride compounds. The reported case files on this type of reaction were limited to a few cases within the metal-processing industry involving low-purity metals.

Soluble beryllium compounds will cause ulcerated lesions when introduced through the skin via cuts or abrasions if not cleaned.

Acute respiratory disease can be caused by brief exposure to soluble compounds capable of depositing within the respiratory system. This disease is characterized by inflammation of the affected tissue anywhere throughout the respiratory system with the serious potential risk of developing pneumonopathy. Two types of acute respiratory illness have been described: (1) a fulminating type thought to be associated with massive single exposures to inhaled soluble aerosols, and (2) a more insidious type thought to be associated with repeated high exposures. Recovery periods have averaged approximately 8 weeks after removal from exposure and initiation of treatment.

Chronic dermal effects were demonstrated by hundreds of cases in the fluorescent lamp industry during the 1940's. This injury is characterized by a gross skin lesion following implantation of soluble beryllium compounds. Surgical incision to remove the offending compound is usually required for a cure.

Chronic respiratory disease has been associated with repeated inhalation of significant airborne concentrations of insoluble beryllium compounds. Major symptoms are development of progressive granulomatous masses in the interstitial tissue and alveolar walls. The latency period between exposure and appearance of disease has varied from months to as long as 23 years. Epidemiological studies of the chronic respiratory disease have been complicated by several factors: (1) the poorly documented data on airborne concentrations of beryllium required to cause the disease, (2) uncertainties in the physical-chemical properties of the beryllium compounds involved, and (3) the apparently low rate of attack in the exposed population. The pattern of disease occurrence in the beryllium processing industry does show that risk is correlated highly with intensity of exposure but not with duration of exposure.

The relationship between the chemical nature of the beryllium compounds that lead to strict control procedures and those compounds associated with rocket motor testing were extensively investigated. Studies were carried out to determine animal response to actual exhaust constituents, to relate acid solubility of the beryllium faction of exhaust products to biological response, and to characterize the beryllium compounds present in the motor exhaust.

Beryllium powder added to solid propellants accounts for approximately 12 percent of the propellant weight. The powder used is chemically graded to reduce impurities and subsieved to grades PS-97 and PS-98 to provide a narrow range of particle size distribution. The theoretical chemical constituency of the beryllium as an exhaust product (using equilibrium expansion to 14.7 psia) is converted to the oxide. Less than 5 percent of the additive weight is converted to the soluble chlorides, in the case of composite propellant formulations. Composite formulations release all of the beryllium as an oxide.

Small quantities of beryllium metal can be released because of combustion inefficiency during a motor firing. Considerable percentages of the metal could be released in case of accidental motor case failure as in any low-pressure propellant burn. Several samples of solid exhaust constituents were obtained close in to the nozzle during motor firings using high mass flow collectors. Analyses of these samples indicated approximately 91 percent of the beryllium present as the oxide, 8 percent as the metal and less than 1 percent as the chloride. These samples may not represent the final oxidation state of the exhaust constituents.

Investigations of beryllium exhaust toxicity were carried out by the Dow Chemical Company, Midland, Michigan (Reference 7). Substantial evidence was produced that showed a wide variation in toxicological response to beryllium oxides formed at low temperatures (500°C) from that formed at high temperatures (1600°C). The so-called "low-fired" beryllium oxide exhibited the same type of chronic lung damage associated with previous industrial experience. However, beryllium oxides calcined at high temperatures were essentially nonreactive and comparable in toxicity to inert dusts. A definite gradation of toxicological response was observed throughout the calcining temperature range from the highly reactive low-fired oxide to the seemingly inert high-fired form. The differences in toxicity closely parallel changes in the chemical-physical properties which occur as calcining temperature changes. As the temperature increases, the degree of crystallinity, average crystalline size, refractive index, and density increase, while the surface area decreases. Current high-performance solid motors subject the beryllium to temperatures above 3000°C during the oxidation process.

BERYLLIUM CRITERIA AND STANDARDS

A variety of criteria relating to permissible airborne concentrations of beryllium were applied to the test program. In addition, standards relating to surface loading of materials and structures were applied to reduce accumulation, prevent the spread of beryllium outside controlled areas and prevent potential resuspension problems.

The original AEC criteria relating to in-plant exposure and neighborhood continuous exposure were applied to the test program. In-plant creteria for workers involved with handling beryllium materials were set at 2 $\mu g/m^3$ averaged throughout a standard 40-hour week. The allowable peak concentration at the breathing zone was set at 25 $\mu g/m^3$ for exposure periods no longer than 30 minutes. Exposure above the 25 $\mu g/m^3$ level was not allowed without appropriate respiratory protection. The neighborhood criteria for continuous off-site exposure was set at 0.01 $\mu g/m^3$ averaged over a period of 30 days.

Permissible surface-loading criteria were based on operating experiences previously obtained by the AEC and Aerojet-General Corporation and the knowledge that these levels were safe by orders of magnitude in terms of contamination migration to clean areas and resuspension. Limits of 25 $\mu g/ft^2$ for controlled surfaces and 5 $\mu g/ft^2$ for hand tools were used to indicate degree of cleanliness. Soil surface contamination was evaluated in terms of potential resuspension of material within the firing grid. Levels above 1000 $\mu g/ft^2$ could possibly be resuspended to an airborne level of 2 $\mu g/m^3$.

The previously cited criteria for airborne concentrations are not entirely applicable to rocket test operations. The neighborhood criteria were developed for beryllium emissions which were uncharacterized as to chemical composition and physical properties. These emissions were continuous without regard to meteorological diffusion conditions and were usually in close proximity to heavily populated areas.

In 1966, the Committee on Toxicology, National Academy of Sciences, National Research Council, completed a reevaluation of beryllium air quality criteria at the behest of the U.S. Public Health Service (Reference 17). Although their recommendations for continuous neighborhood exposure remained the same, they recommended additional criteria for intermittent exposures resulting from rocket motor tests. The basis of the new criteria was that: (1) rocket motor testing can be controlled in frequency, (2) the resulting exposures would be intermittent and of short duration, (3) test firings would be made only under optimal meteorological conditions with an extensive monitoring control system, and (4) a large percentage of the beryllium in the exhaust is high-fired oxide.

The following specific criteria were presented in that document:

(1) For soluble beryllium compounds, a maximum exposure of 75 $\mu g/m^3$ could be applied within the limits of 10 to 60 minutes accumulated during only 2 consecutive weeks. This limit was based on a safety factor of 10 for the proven safe industrial level of 25 $\mu g/m^3$.

(2) For beryllium oxides occurring in rocket exhausts, a maximum dosage of 1500 $\mu g/min/m^3$ could be applied within the same time constraints. This level was based on the consideration that beryllium in rocket exhausts has been shown to be predominantly crystalline beryllium oxide with physical-chemical characteristics of the high-fired oxide.

(3) For beryllium compounds in rocket exhausts which are a mixture of soluble compounds, and low-fired oxide and high-fired oxide, the dosage limits could be based on the percent acid solubility of the beryllium components. When the rocket effluent contained beryllium compounds which were acid-soluble (36 percent HCl diluted 1:1) in amounts less than 1 percent, the high-fired limit applied. For acid solubilities in the range of 1 to 5 percent, a limit of 750 $\mu g/min/m^3$ was proposed; and for solubilities greater than 5 percent, the low-fired dosage limit was proposed. The same intermittent time constraints were applied to this combination dosage limit.

OPERATIONAL CONTROL

Operational control of the project constituted one of the major bioenvironmental efforts in support of this test. An extensive educational program was initiated prior to the first beryllium involvement so that both the laboratory management and project personnel would be aware of the hazards involved and the necessary control procedures. A detailed document covering in-house procedures was drawn up and disseminated throughout the laboratory and eventually incorporated as the guiding operations procedure for all laboratory beryllium programs. Special briefings on specific beryllium control measures were given to project personnel. The enlightened cooperation of all people associated with Project ADOBE was a major factor in the ultimate safe conduct of the program.

All motors tested on this program were received from the major suppliers premixed and cast in lined segments. This procedure minimized one of the major beryllium suspension problems inherent in this type of test program. Plastic end caps were used to prevent accidental dissemination of the propellant in case of rough handling leading to grain failure. Motors were built-up to firing capability in a motor assembly building where the segments were inserted into a liner and placed in a motor case. Nose and tail domes and nozzle were then attached to the motor case. Adequate storage capability was provided for unassembled motor grains in a series of ground-covered explosive igloos.

Assembled motors were transported under escort to the test stand with an additional plastic end cover over the nozzle to provide containment in case of accident. Once on the stand, the motor was hooked up to instrumentation and readied for firing. The electrical initiator was not installed until immediately prior to firing. The prefiring assembly portion of the test program did not cause industrial hygiene problems because the propellant grain remained relatively undisturbed and inviolate.

The firing sequence was controlled by a strictly ordered countdown to firing and through meteorological controls described elsewhere in this report. The progress of each test was monitored by the Operations Control Office which had hot-line communications with the test blockhouse. Access to the firing grid was controlled by fencing and the use of two selected entry gates. All personnel entering the grid were required to sign in and out, and this information was passed to the Operations Control Office. The entire grid was verified to be empty of personnel prior to each test. All test area personnel were withdrawn into the blockhouse prior to testing and for a reasonable time period after testing.

Re-entry into the test stand area was accomplished by two red-crew members (project engine mechanics) who were responsible for putting out any brush fires started by the motor firing and safetying the initiator. These individuals wore appropriate protective equipment and were in constant commumication with test personnel in the blockhouse.

The motor case assembly was allowed to cool sufficiently so that water washdown would not cause steam generation of a beryllium aerosol. The entire outer motor assembly, thrust stand and hard surface test stand were washed down with water to a waste holding pond which was never allowed to dry out. The motor assembly and nozzle were then covered with a plastic bag until the next day.

Dissassembly was accomplished by removing the nozzle, aft and fore closures and the chamber liner. The nozzle was steam cleaned and bagged for shipment to the contractor. A typical steam-cleaning operation by a crew member is shown in Figure 21. The end closures were stripped of insulation, which was bagged for disposal, and the metallic surfaces were steam cleaned. The chamber liner was forced out and bagged for disposal and the chamber was steam cleaned for transport back to the motor assembly building. The test stand and associated equipment were washed down as a final step of each disassembly.

Project technicians responsible for maintaining the diffusion grid incurred potential exposures to resuspended beryllium dust and contact with particles deposited on equipment surfaces. These technicians traveled extensively over the dirt road network which serviced the sampling grid. Control measures included grading and wetting the dirt roadways, personal protective equipment, a change trailer and a vehicle wash rack. Equipment such as batteries and samplers removed from the grid were processed through a wash facility to remove surface contamination. All personnel entering the operations and grid areas were processed through decontamination trailers which included clothing issue, lockers and hot

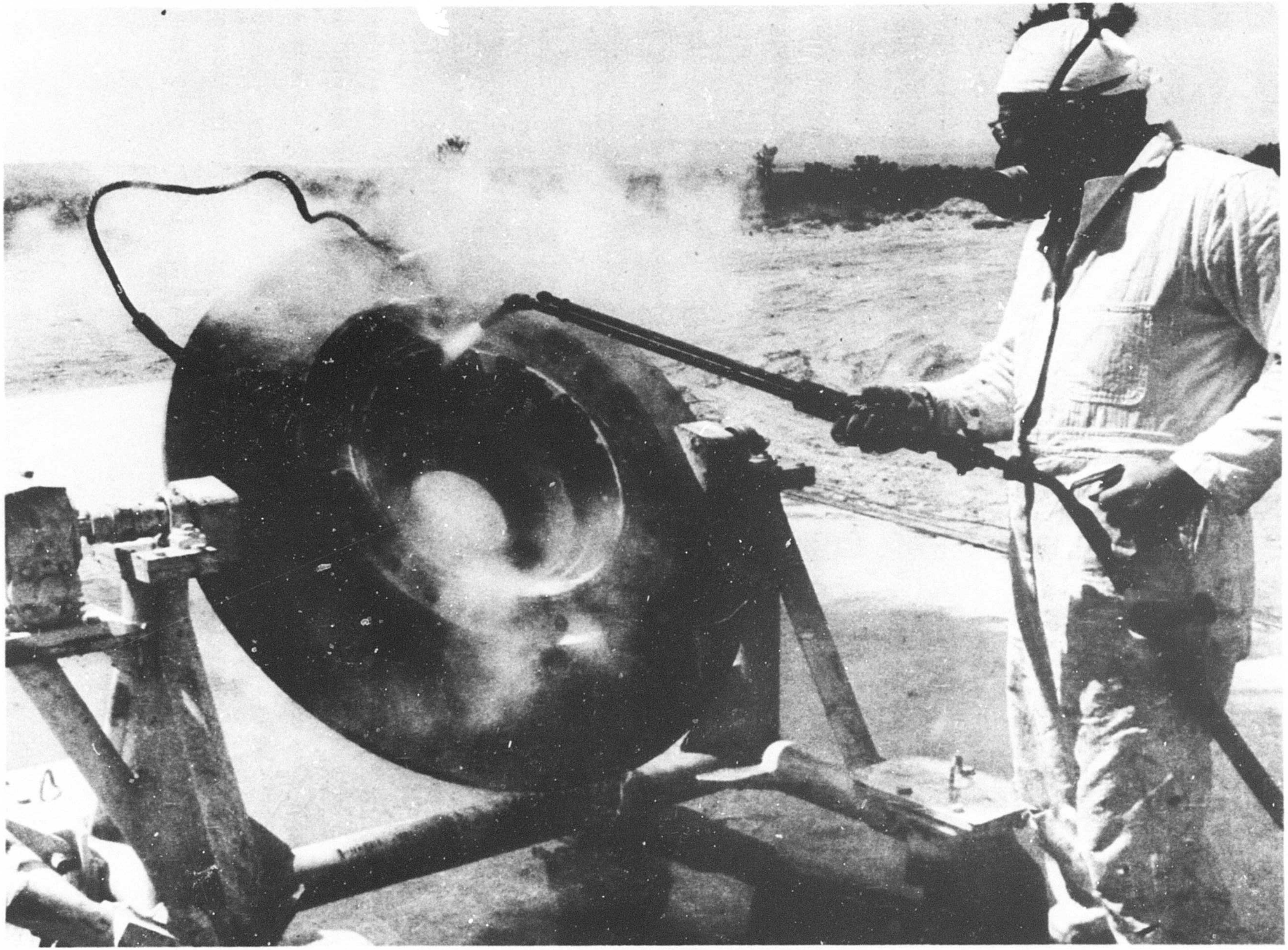


Figure 21. A Typical Steam Cleaning Operation

showers. Clothing was issued on a daily basis and used clothing was bagged for cleaning or disposal. Respirators were issued on an individual basis and washed periodically with soap and water to maintain hygienic conditions.

Complete protective clothing ensembles were required for operations on the firing pad and downrange grid areas as shown in Figure 22. White cloth coveralls were worn over seasonal undergarments. Disposable plastic gloves were used for hand protection with surgeon's gloves used for precision manipulations. Either plastic or paper booties were used over safety shoes. Head covers were surgical-type disposable paper. Respiratory protection for routine operations was provided by American Optical twin-filter respirators with high-efficiency R-57 filter cartridges. Both the open-face model and combination eye protection respirators were used during this program. Relatively high-risk operations such as clean-up after motor failure or wire brushing of contaminated surfaces required the use of a Scott Air Pak supplied air system.

Beryllium contaminated waste material from this program consisted of systems hardware, washdown effluent, disposable protective equipment, and paper goods used for cleaning and analytical chemistry work. Hardware which was not required anymore was allowed to weather at a site downrange of the firing stand and was ultimately disposed of by a licensed contractor. All other disposable goods were double-bagged in plastic and also disposed by contract. Water effluents from washdown operations and analytical work were impounded, both to localize the area of contamination and to provide long-term particulate settling. These ponds were located in relatively impermeable soil strata with no known intrusion route into a drinking water table.

Medical surveillance of people associated with the program included preplacement selection, periodic physical examinations, return-to-work examinations and instructions in symptomology and first aid. Preplacement

Figure 22. Personnel Protective Clothing Ensemble

examinations included a thorough history to include implications of allergenic susceptibility and chest X-rays to provide a pre-exposure reference. Individuals with a history of serious allergies, pre-existing pulmonary pathology, or those presenting X-ray abnormalities were not accepted for the program. Periodic medical examinations consisted of a monthly weight loss chart and yearly re-examinations of history, chest X-ray and vital capacity. Post-absence examinations were required for personnel returning to work after prolonged absence. Implications of surgery or illness to potential beryllium exposure were evaluated at that time. In general, all personnel were advised to seek medical aid for any related symptomology, to maintain sterile dressings over cuts and abrasions, and to obtain first aid for any injury associated with beryllium work.

MONITORING PROGRAM

The environmental monitoring program was designed to provide extensive data on exposure conditions resulting from the test program, both for in-plant project personnel and for downwind and populated areas. The program included fixed, air-sampling stations for evaluation of average concentration trends, high-volume air sampling of selected operations, personnel air sampling for specific job tasks, wipe sampling in support of contamination control and disposal beryllium exhaust solubility and particle size, and comparisons of soil loading with resuspension.

The basis of the monitoring system was a network of fixed, air-sampling stations located as shown in Figures 23 and 24. Several beryllium firing programs were conducted concurrently with ADOBE, and sampling positions TA 11, 12, 13 and 14 were used primarily for monitoring those other programs. Sampling positions TA 7 and 8 were used primarily to monitor resuspension of beryllium particulate. The remaining area sampling stations were located at the AFRPL firing positions which constituted the major in-house population centers.

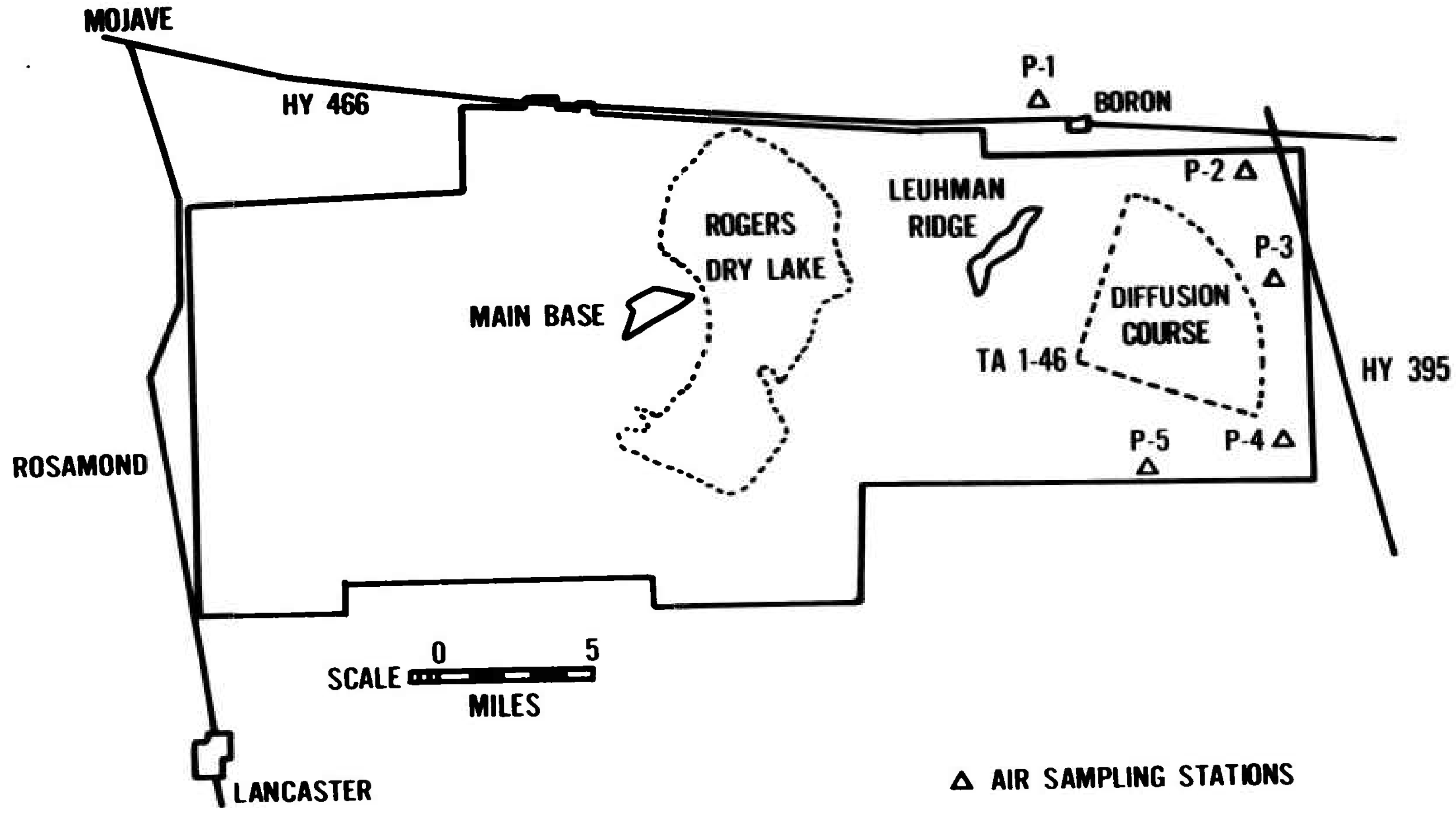


Figure 23. Perimeter Monitoring Stations

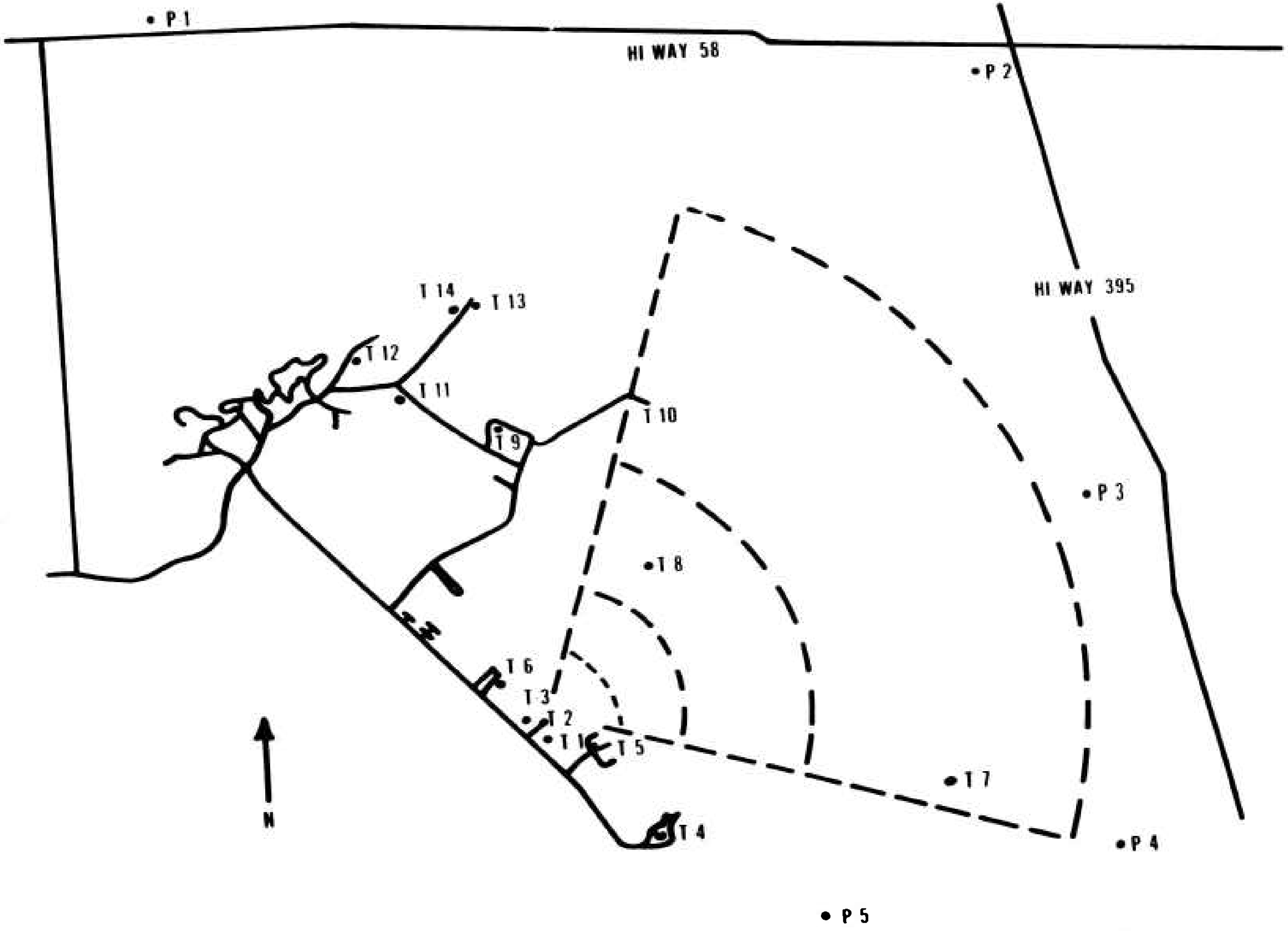


Figure 24. Test Area and Perimeter Air-Sampling Network

The perimeter air-sampling network, as shown in Figure 23, was used to evaluate the degree of hazard to off-site populations both in downwind communities and on the major close-in highways. At stations P-2 and P-3, two samplers were used at each station to compare variation of sampling efficiency with flow rate.

Both the area and perimeter monitoring stations consisted of medium flow rate particulate samplers housed in modified U.S. Weather Bureau instrumentation shelters. A typical monitoring station is shown in Figure 25. These wooden shelters were sized up from the standard design to increase equipment space and were fabricated in-house. All shelters were located to minimize terrain and building effects between the firing positions and the sampling stations. The samplers were housed horizontally at 4-1/2 feet above ground surface with the filter side located toward a louvered door which faced the rocket motor firing position. Sampler exhaust was ducted through the downrange louvered side of the shelter to minimize particulate re-entrapment and turbulent eddy effects within the shelter.

The samplers were automatically turned on and off by using AC-powered 24-hour interval timers ganged to the sampler on-off switch and internal cumulative timing device.

The samplers used in both the area and perimeter monitoring stations were primarily Filtronics CP 750's with additional Gelman Tempests (Model 18005) located at stations P-2 and P-3. The Filtronics CF-750 is an electrically driven, dual-turbine air mover with constant air-flow compensation. The 9/16 horsepower electric motor varies speed according to the static pressure drop across the filter surface. As surface loading increases, the motor increases rpm to maintain constant flow. Flow rate settings are made by adjustable rotameter. The Gelman Tempest is a carbon-vane rotary driven by a 3/4 horsepower VAC motor with a free air capacity of 10.5 cu ft/min. These samplers are capable of 24-hour-per-day

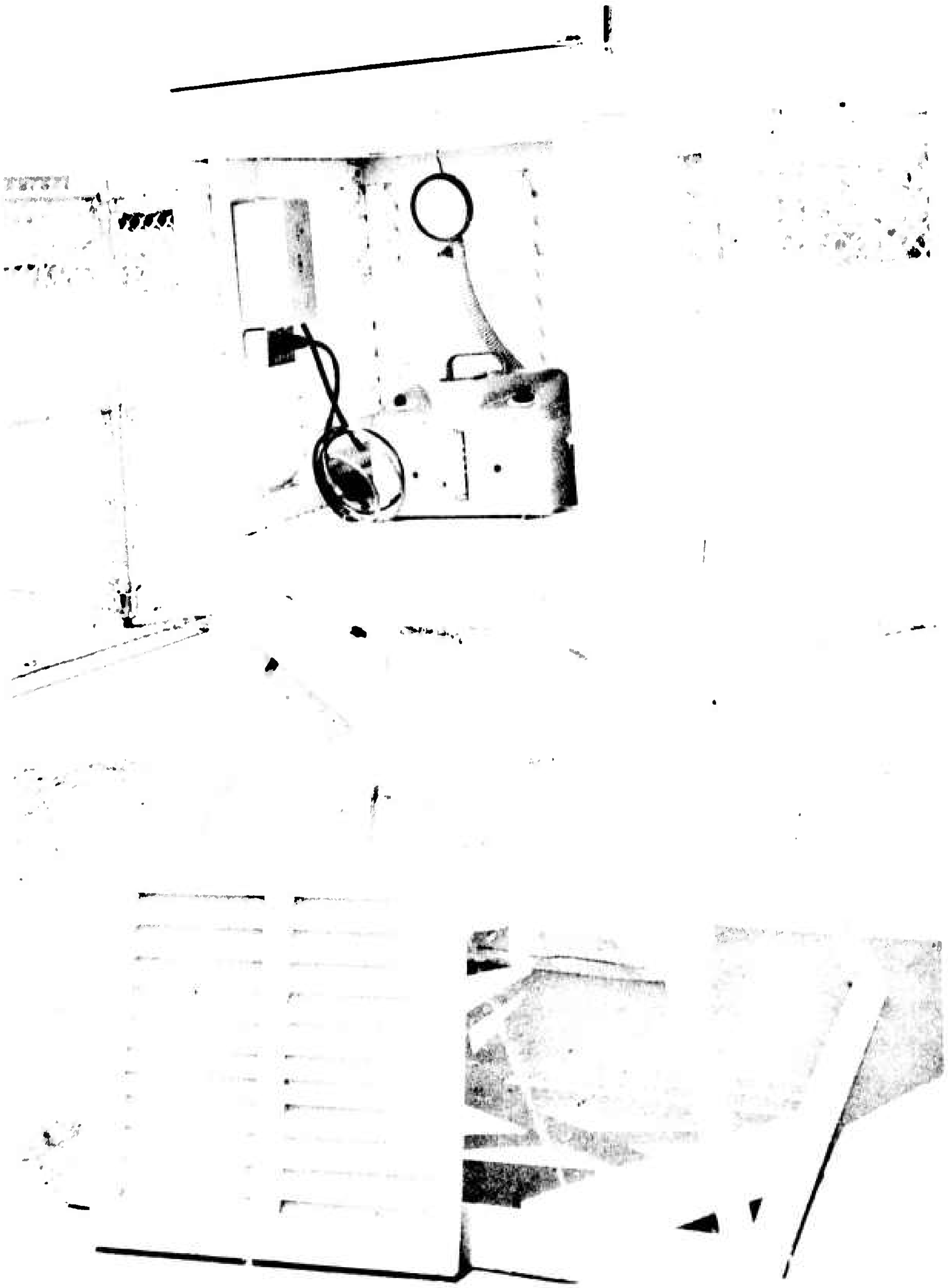


Figure 25. Instrumentation Shelter

operation indefinitely and have built-in heat overload protection but do not have an air-flow compensation system.

Area and perimeter stations were operated 12 hours per day (10:00 AM to 10:00 PM) and 7 days per week, and were serviced twice weekly for routine filter changing and sampler station maintenance. The samplers were fitted with 4-inch-diameter filter heads threaded to the pump intake. Filters were supported from behind by screens and bar supports to avoid damaging the relatively delicate membranes. A typical dismantled filter head is shown in Figure 26.

Sampler maintenance consisted mainly of periodic calibration and replacement of carbon vanes. Electrical motor overheating was an infrequent factor in sampler breakdown despite the high ambient temperatures prevalent in this region. If overheating had proved to be a major factor, it was planned to operate the sampler at reduced rpm and lower flow rates.

Initially, all air-flow calibration was carried out at 6-month intervals using the setup shown in Figure 27. The calibration procedure consisted of using a venturi meter as a secondary calibration device and simulating filter pressure drop with a 115 VAC Variac. The sampler rotameter was adjusted to agree with the calibration value. The venturi meters were calibrated yearly against a primary standard, namely a spirometer made available by the Precision Measurement Equipment Laboratory, McClellan AFB. Appropriate temperature, pressure correction factors were used to relate the primary standard calibration to the Edwards AFB environment.

During 1967, a series of calibration comparisons between methods which vary motor speed (Variac) and those which vary resistance at constant motor speed, led the laboratory to the same conclusions reported by Lynam (Reference 18). In that report, the investigators found that the two methods can produce quite varying calibration results and that the Variac method was valid only if the filter to be used in the field was used during

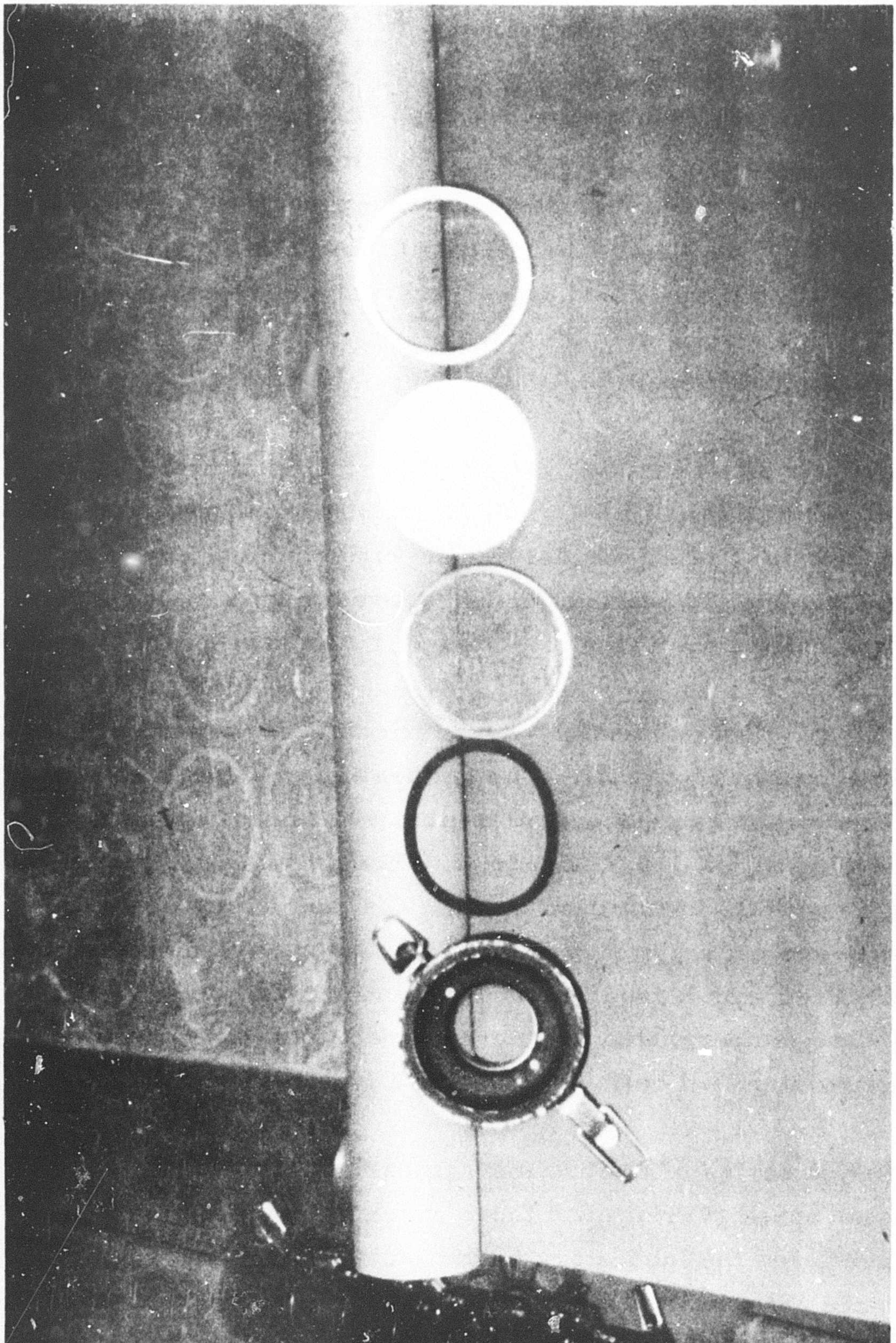


Figure 26. Dismantled Filter Head

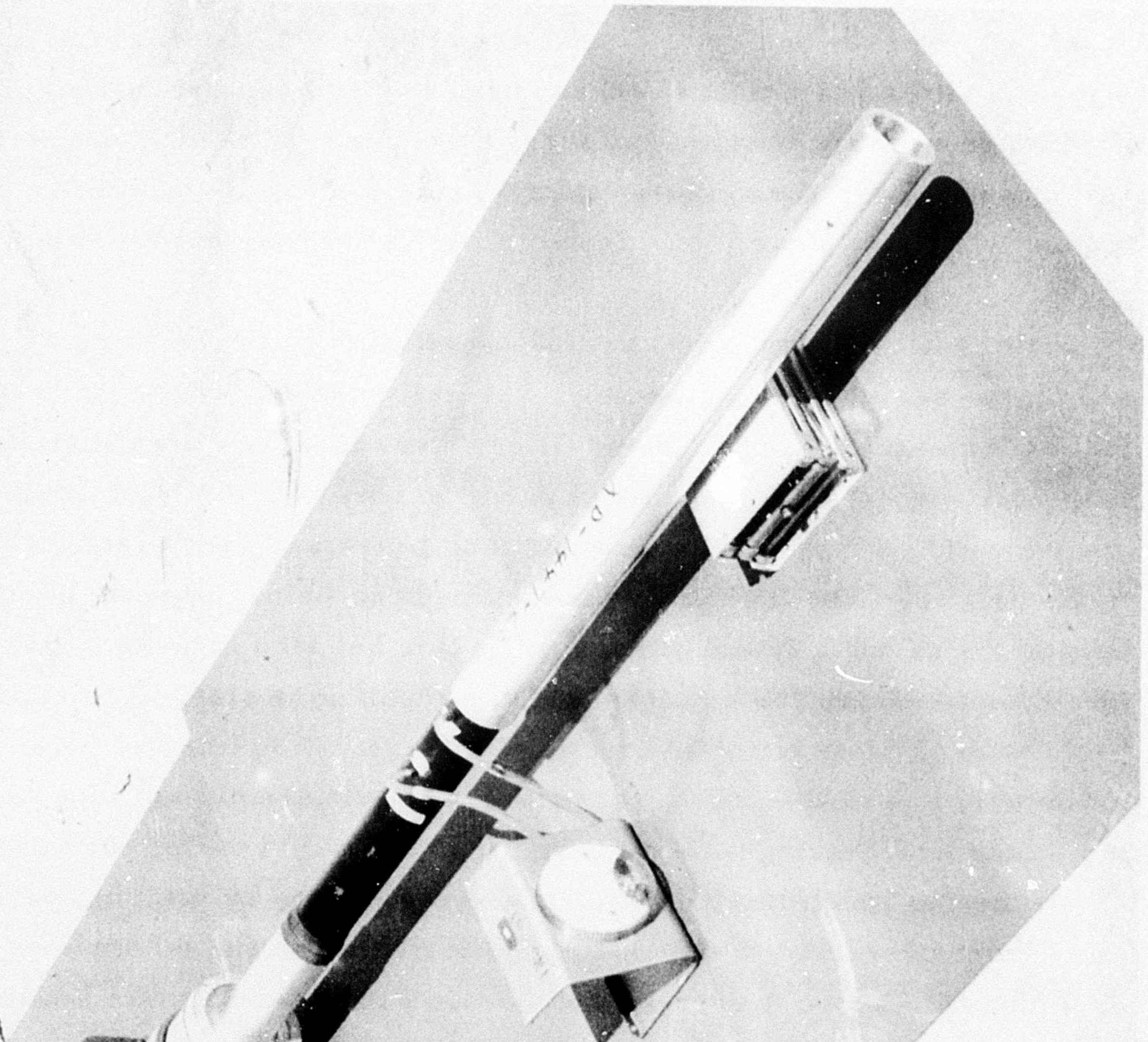


Figure 27. Air-Flow Calibration Apparatus

calibration and if the motor speed was varied over a relatively narrow range. Our results led us to change the calibration procedure to one using a range of filter resistances and ensuring that the venturi-to-sampler transition stage reduced spurious effects of the inherent venturi pressure drop. Shortly thereafter, the venturi meter was replaced with a laminar flow element which completely eliminated spurious pressure-drop effects.

Filters used for the air-monitoring network were the same as those used on the sampling grid, namely, specially graded Millipore Corporation SMWP membrane filters. These filters were ideal for beryllium sampling in several respects. The uniformity of the pores (5 ± 1.2 microns) and the high-porosity promotes excellent particulate trapping with reasonably high air-flow rates. The high specific surface area helps generate electrostatic charges which not only aid surface retention but also increase filter efficiency for particles far smaller than the mean pore size. The capability of this type of filter to inhibit particulate penetration into the filter is undoubtedly one of the major reasons why the filters did not clog and sampler motor overheating was not a major problem. The delicacy of these membranes to rough handling was mainly overcome by training personnel to use them correctly, by preloading filter heads in the laboratory, and by using adequate support screens and bars. Filter tearing was a minor annoyance and invariably caused by improper loading procedures.

In addition to the fixed, air-sampling network, a variety of work situations was monitored to provide specific exposure data on motor-handling operations. The nature of the potential exposure during these operations would be exposure to relatively brief but intense airborne concentrations in case of mishandling of the motor or significant beryllium residue after firing. These situations were monitored using high-volume samplers for periods of up to 60 minutes. The samplers used in this case were either the Staplex Model TF-IA or the Unico Model 600 Turbine-Jet. These samplers were mounted on metal stands fabricated in-house which allowed the samplers to be placed at the desired monitoring position and fixed them at

4.5 feet aboveground. These samplers were used with 4-inch-diameter filter heads and Millipore Corporation SMWP membranes which produced flow rates of 12 to 14 cu ft/min. Proper filter support for these sampler heads was more critical because of the higher pressure drops across the filter face. Maintenance and calibration of these samplers were carried out on an as-needed basis but at least before each major sampling operation.

Estimates of individual exposure were made using battery-operated lapel samplers. Samplers used for these purposes were the Filtronics Model BC-35 and the MSA Monitaire. These samplers were issued on an individual basis for the duration of a specific operation. Both samplers use small (approximately 1-inch) filter holders backed by a spring clip which can be attached to a worker's outer garment near his breathing zone. The filter holder is connected by polyethylene suction tubing to a battery-operated pump which can be attached to a belt or coverall pocket. These pumps produce pressure drops of 0 to 10 inches of water which is not sufficient to pull through a high-resistance membrane filter. Therefore, Whatman-41 filter sheets were punched to the proper size and backed by a metal screen for these samplers. Flow rates in the field using this filter paper were in the range of 3.0 to 3.5 LPM and were maintained by means of an adjustable rotameter incorporated in the pump. Calibration of these devices posed a challenge in that the filter holders could not be incorporated into a flow-measuring train behind the secondary flow calibration device. Initial attempts at calibration were to use a spirometer, constructed in-house, to directly correlate flow with the adjustable pump rotameter reading, or to use the sampler filter holder with filter and suction tubing on the intake side of a wet test meter. Although these methods correlated well with each other, they did not represent actual sampling train losses present in the field. The final technique was to use an enclosed filter holder on the exhaust side of a wet test meter using the same filter and same length of tubing used in the field. This last procedure did not significantly change calibration results which probably indicates that any of the methods was sufficiently accurate for this type of sampling device.

In addition to monitoring of airborne concentrations of beryllium compounds, the potential for regeneration from surfaces was evaluated through wipe and soil samples. Wipe samples were used to evaluate contact hazards from the firing stand and associated hardware, and to ensure adequate cleanliness of decontaminated parts before removal from the test area. These samples were taken with Whatman-40 or -41 filter paper using moderate surface pressure over an area of 1 sq ft whenever possible. Surfaces were wiped in one continuous motion from outside to inside without going over any specific spot more than once. Filters were folded once along the diameter and refolded in half before being inserted in a plastic bag for subsequent analysis. The utmost care was required in handling surface wipe filters to avoid unintentional loss of sample and cross-contamination.

Soil samples were analyzed to investigate long-term environmental effects of beryllium particulate fallout and to analyze the potential resuspension from downrange surfaces. These samples were taken out to 9600 meters at several hundred points on the diffusion grid where the particulate would be expected to impinge or fall out. The initial series of soil samples was taken before the firing program began to establish background; a second series was taken midway through the program, and a final series was run to look at the total effect of the program. Two types of soil samples were taken. The first was a 1 sq ft sample removed to a depth of 1 inch by use of template and spatula. This type of sample was analyzed in terms of micrograms of beryllium per gram of sample (ppm by weight). The second type was by the use of sticky paper to evaluate the depth of migration of the beryllium particles through the soil. These samples were also 1 sq ft in area and were taken using a long-handled roller as shown in

Figure 28. The sticky paper was rolled one time over the 1 sq ft area; then additional single rolls were taken with different pieces of sticky paper up to 10 rolls over a given spot. These samples were analyzed in micrograms of beryllium per square foot.

PERIMETER SAMPLE RESULTS

Perimeter sampling stations were arrayed as shown in Figure 23. In addition to these five stations, a monitoring station was activated at the Marine Corps Supply Center, Barstow, California, from September 1966 to the end of the program. This station was located some 40 miles east of the Laboratory and was used to analyze long-range fallout effects. All sampling stations were operated for more than 1 year after the last firing test to see if significant migration or resuspension occurred, and because large quantities of beryllium propellant were still stored at the AFRPL.

The perimeter monitoring results are shown in tabular form in Table XIII. These results are in terms of average concentrations per month calculated from the total beryllium content and total flow volume obtained by the semiweekly samples. The monitoring stations were operating during all firings except for the six 15-pound motors which were intentionally fired under inversion conditions. According to diffusion calculations and actual results obtained from the grid sampling network during inversion firings, the quantity of beryllium reaching the Laboratory perimeter was undetectable.

Figure 29 shows a plot of quantities of beryllium fired by month compared with the highest monthly average concentration obtained by any of the perimeter stations during the same month. Station P-3/3T, which was located on the center radial (45°TN) of the firing grid, accounted for 21 of the high average concentrations during the 37-month test period. There is very good general agreement between the quantities of beryllium released and the perimeter monitoring results, especially when considering the vagaries of quasi-instantaneous puff source releases under a

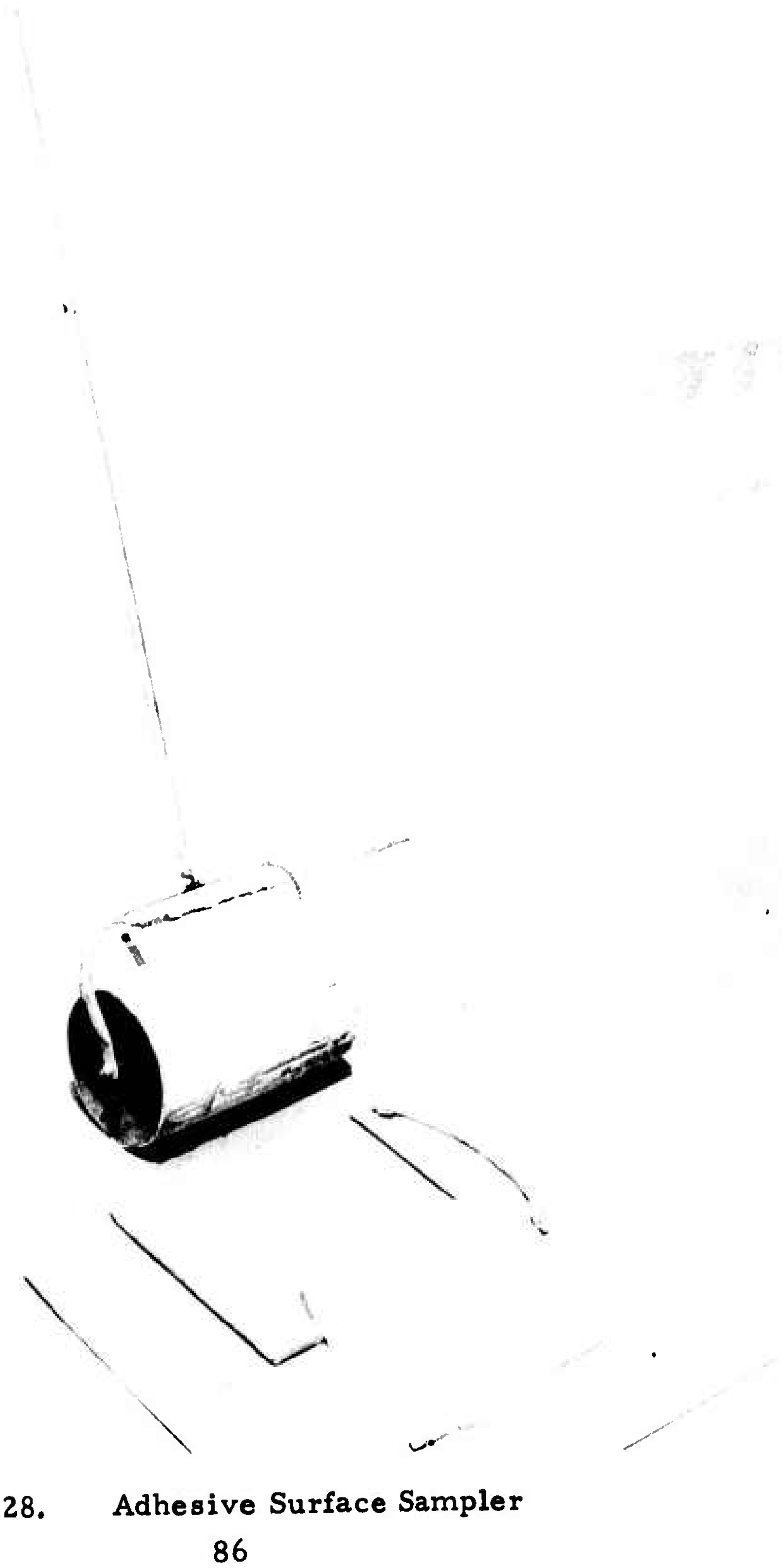


Figure 28. Adhesive Surface Sampler

TABLE XIII. PERIMETER SAMPLE RESULTS, MONTHLY AVERAGES*

Month and Year		P-1	P-2	P-3	P-3T	P-4	P-4T	P-5	Barstow
Sept	1964	L.T.D.**	L.T.D.	0.885		L.T.D.		L.T.D.	
Oct	1964	L.T.D.	L.T.D.	L.T.D.		L.T.D.		L.T.D.	
Dec	1964	12.7	1.26	6.91		13.0		4.42	
Jan	1965	2.18	1.77	2.96		2.25		0.877	
Feb	1965	0.761	L.T.D.	122.0		L.T.D.		0.693	
Mar	1965	0.899	0.289	48.0		1.10		2.16	
Apr	1965	1.80	0.609	1.93		0.725		0.892	
May	1965	0.150	3.72	2.65		1.32		18.0	
Jun	1965	1.17	1.32	99.1		0.158		L.T.D.	
Jul	1965	0.114	0.556	5.60		0.444		0.129	
Aug	1965	5.12	18.6	179.0		21.3		7.02	
Sept	1965	14.4	8.71	14.7		0.865		9.05	
Oct	1965	4.54	3.15	4.20		4.70		3.69	
Nov	1965	2.91	2.86	7.62		1.20		2.11	
Dec	1965	5.31	3.41	12.1		10.8		1.72	
Jan	1966	0.611	0.508	0.800		0.340		0.722	
Feb	1966	1.67	1.47	8.55	0.640	2.32		3.98	
Mar	1966	1.46	1.85	8.32	6.45	2.07	0.557	2.29	
Apr	1966	54.7	57.5	83.4	36.6	24.2	28.7	17.7	
May	1966	3.01	8.86	72.9	64.9	1.89	2.57	4.96	
Jun	1966	14.6	5.61	167.0	179.0	7.45	7.81	5.39	
Jul	1966	7.54	6.51	12.0	13.3	12.8	13.6	8.79	
Aug	1966	10.5	7.14	5.10	19.2	14.9	17.8	6.44	
Sept	1966	4.37	9.64	15.2	15.8	5.77	5.78	4.67	5.20
Oct	1966	5.89	3.25	6.91	4.99	7.62	6.63	5.63	3.68
Nov	1966	2.71	1.49	3.24	5.75	3.36	2.99	1.80	1.31
Dec	1966	1.27	3.34	2.60	1.39	1.61	1.67	4.28	74.4
Jan	1967	4.17	5.95	2.92	3.20	3.17	2.45	0.719	1.26
Feb	1967	2.54	6.06	8.34	4.26	5.32	2.10	2.79	1.33
Mar	1967	1.67	4.31	5.64	5.02	8.17	3.64	4.05	5.55
Apr	1967	2.04	4.81	11.9	13.4	9.06	2.93	2.45	2.05
May	1967	2.24	1.10	0.837	0.711	0.906	0.602	1.78	1.18
Jun	1967	2.21	1.91	1.95	1.86	0.396	0.342	0.637	0.686
Jul	1967	4.76	0.651	2.05	1.88	2.27	2.10	1.37	3.53
Aug	1967	3.23	5.86	4.18	4.72	3.41	54.8	2.68	3.48
Sept	1967	2.07	8.66	2.59	2.77	2.78		1.91	0.707
Oct	1967	12.9	9.33	32.0	31.7	10.4		17.4	3.82
Nov	1967	2.66	7.16	2.55	2.05	9.11		4.06	2.57
Dec	1967	4.63	5.62	3.91	3.22	4.91		3.82	6.08
Jan	1968	7.16	2.69	5.75	3.48	5.84		5.28	3.53
Feb	1968	8.47	4.23	7.20	3.33	3.63		5.46	3.49
Mar	1968	8.48	4.55	9.47	5.81	10.4		8.66	15.3
Apr	1968	20.5	6.10	170.0	52.2	11.1		12.0	4.17
May	1968	7.89	4.04	8.30	5.63	10.2		9.34	3.90
Jun	1968	9.02	4.41	9.94	52.7	8.74		9.14	28.9
Jul	1968	25.2	7.98	12.5	39.2	11.1		11.6	14.6
Aug	1968	9.95	4.38	15.6	35.0	11.4		14.4	3.92
Sept	1968	11.8	4.28	9.58	23.0	9.51		14.4	4.94
Oct	1968	5.32	2.45	5.49	12.1	4.68		6.04	2.42
Nov	1968	3.16	7.48	3.47	10.1	4.77		3.65	3.41
Dec	1968	3.69	1.84	1.31	14.6	2.70		2.55	2.06
Jan	1969	3.01	1.93	4.63	14.4	3.98		2.69	1.38
Feb	1969	3.74	2.40	4.36	13.41	3.29		4.98	1.63
Mar	1969	3.84	2.19	3.88	2.45	4.16		6.42	2.46
Apr	1969	2.99	1.42	3.63	1.43	2.52		2.84	5.19
May	1969	3.09	2.61	3.30	1.66	3.35		6.20	3.04
Jun	1969	3.81	1.89	4.40	2.17	4.48		4.61	4.77
Jul	1969	3.80	1.88	4.06		4.66		4.36	3.48
Aug	1969	4.11	2.93	4.59		6.86		5.71	3.61
Sep	1969	4.28	3.87	4.10		4.40		3.21	5.70
Oct	1969	7.42	8.02	6.40		6.40		7.20	4.91
Nov	1969	L.T.D.	L.T.D.	L.T.D.		L.T.D.		L.T.D.	L.T.D.
Dec	1969	L.T.D.	L.T.D.	L.T.D.		L.T.D.		L.T.D.	L.T.D.

* Measured in μg Be/m^3 X 10^4.

** L.T.D. indicates less than detectable.

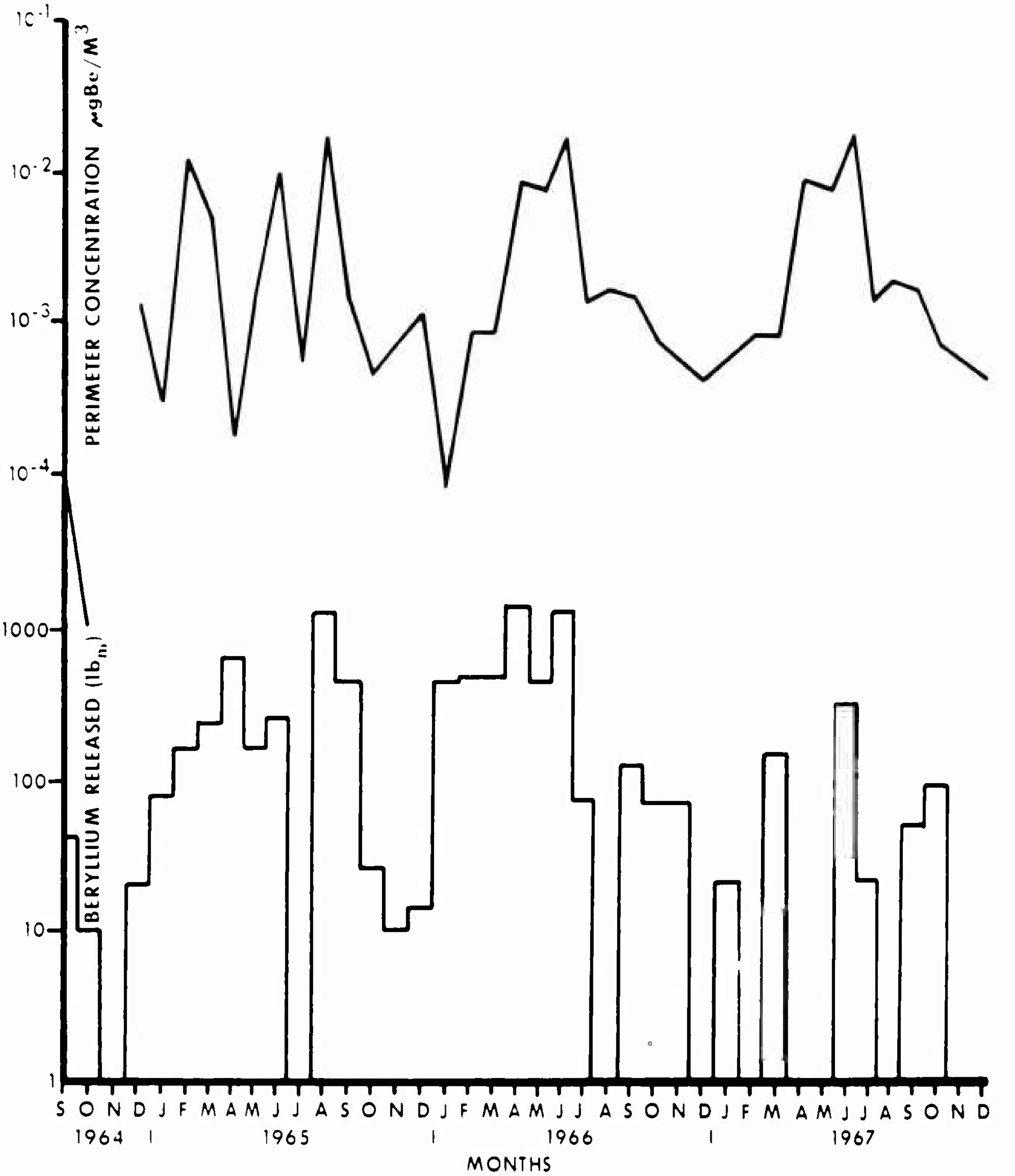


Figure 29. Monthly Comparisons of Beryllium Release and Perimeter Concentrations

wide range of atmospheric turbulence conditions. In general, quantities of beryllium over 1200 pounds per month, which were released in three separate motor firings, caused overage concentrations near 0.01X $\mu g/m^3$ during the sampling period. The sampling period is emphasized in light of the long-term neighborhood criteria which relate to a continuous 24-hour sampling period. If the perimeter samples had been allowed to obtain dilution air during periods of nonactivity, the average 24-hour results would have been reduced below the reported concentration values by approximately a factor of 2. Figure 29 also indicates that monthly release quantities in the range of 10 to 100 pounds generally resulted in average concentrations one order of magnitude above background, and releases in the range of 100 to 1000 pounds resulted in average concentrations two orders of magnitude above background.

The perimeter results at P-3/3T for April through September 1968 indicate that there was substantial migration and resuspension of beryllium particulate approximately 6 months after the last firing during a period of total inactivity. The most rational explanation for these results appears to be the unusual weather conditions encountered during early 1968. The laboratory experienced substantial rainfall in February, March and April 1968, which may have caused percolation of previously covered particulate to the surface. One investigation of this phenomena was conducted in-house in an attempt to determine the rate of downward migration of beryllium through local soils. It was found that slight addition of water reversed the course of downward migration and percolated the beryllium back to the soil surface. The usual gusty spring and summer winds in this desert area were quite severe during 1968, with peak wind speeds ranging from 19 to 50 knots during every day of the April-to-September period. These winds were quite capable of resuspending any micron-sized particulate that may have resurfaced.

TEST AREA SAMPLE RESULTS

Test area sample results are given in Table XIV. The sampling station locations and operating conditions were shown in Figure 24. The lower limit of detectability for these samples was generally 0.001 $\mu g/m^3$.

Almost all of the results in Table XIV are in the range of 0.000X to 0.00X $\mu g/m^3$. Only eight samples above this range were associated with the ADOBE program. The highest monthly average sample result was 0.204 $\mu g/m^3$, which was observed in May 1965. The other excursions above 0.01 $\mu g/m^3$ were usually associated with increased test stand activity and large quantities of beryllium fired (400 to 1200 pounds per month). None of the single samples (4-day) approached the threshold limit value level of 2 $\mu g/m^3$.

LAPEL SAMPLE RESULTS

A summary of personal lapel sample results is categorized by task in Table XV. These results are tabulated by the number of results within a given concentration range with the higher results broken down into a concentration range. In general, results less than 0.5 $\mu g/m^3$ indicate that the samples were not significantly different from background. Results in the range of 0.5 to 2.0 $\mu g/m^3$ indicate that the task evolved low concentrations of beryllium. Results above the 2.0 level indicate that substantial quantities of beryllium were generated and that a potential personnel hazard would have existed without the use of protective equipment. All of these results were obtained with personnel in full protective clothing using either ultrafilter or supplied with air respiratory protection, and as such, represent potential exposure conditions rather than actual exposures.

The grid recovery data includes results for operations such as traveling along along dirt roads on the sampling grid, removing used filter heads from samplers, and servicing the batteries which were used to power the samplers. The data shows that most of the time these tasks did not involve

TABLE XIV. TEST AREA SAMPLE RESULTS, MONTHLY AVERAGES*

Month and Year		T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10	T-11	T-12	T-13	T-14
Sep	1964	3.79	55.6	11.0	5.35	L.T.D.	L.T.D.	L.T.D.	L.T.D.	L.T.D.					
Oct	1964	L.T.D.	L.T.D.	L.T.D.	L.T.D.		L.T.D.	L.T.D.	L.T.D.	L.T.D.					
Dec	1964	5.96	3.19	5.43	3.38		4.19	9.16	0.55	4.96					
Jan	1965	2.48	1.07	3.53	L.T.D.		2.10	2.87	1.00	0.630					
Feb	1965	5.55	4.00	41.1	4.18		1.11	0.913	0.262	0.976					
Mar	1965	1.17	3.66	2.50	0.317		0.510	0.478	0.227	0.442					
Apr	1965	12.9	13.7	19.5	0.710	12.0	1.39	15.5	0.047	0.494					
May	1965	2043.0		39.0	0.198	11.2	50.8	1.63	0.204	18.3					
Jun	1965	1.56	32.5	0.224	0.192	3.95	2.14	1.18	0.045	1.41					
Jul	1965	14.5	500.	8.17	5.69	2.90	1.60	1.78	7.00	2.73					
Aug	1965	27.1	34.2	140.0	6.71	4.00	23.7	3.37	37.8	2.92					
Sep	1965	23.8	29.3	140.7	23.1	4.65	3.55	10.2	15.1						
Oct	1965	7.20	22.0	46.7	5.50	6.47	4.70	3.92	6.42						
Nov	1965	2.01	10.8	19.2	2.30	5.67	2.12	2.98	2.59						
Dec	1965	7.75	5.32	5.98	5.09	1.38	2.65	3.86	3.40						
Jan	1966	0.974	12.1	54.5	0.917	0.868	0.657	0.452	0.472						
Feb	1966	7.12	48.5	154.6	2.94	2.73	2.38	2.46	3.23						
Mar	1966	7.19	28.5	385.0	5.47	1.20	1.21	4.95	33.0						
Apr	1966	9.72	52.9	146.6	7.14	9.51	5.87	7.01	7.75						
May	1966	6.86	34.5	42.7	5.91	4.90	5.69	4.37	6.03						
Jun	1966	13.7	51.6	74.3	6.49	9.53	6.28		Discontinued						
Jul	1966	8.47	14.3	19.1	6.57	3.85	8.99								
Aug	1966	18.9	65.2	44.1	10.3	8.67	3.35								
Sep	1966	4.29	57.9	84.1	6.49	1.38	2.55								
Oct	1966	5.74	41.7	44.8	6.20	5.43	3.31								
Nov	1966	1.42	5.20	12.0	8.58	1.50	2.44								
Dec	1966	1.61	2.65	100.4	1.21	0.790	1.67								
Jan	1967	2.26	5.12	9.94	3.90	7.96	1.59								
Feb	1967	27.6	33.7	19.5	Discontinued	3.51	17.2								
Mar	1967	5.81	8.83	3.10		7.51	11.4								
Apr	1967	2.48	3.12	5.92		9.56				5.51	4.66	1.48	7.31	8.50	
May	1967	11.2	28.6	8.00		1.99				0.480	1.41	1.43	1.92	1.61	
Jun	1967	2.44	4.70	13.7		9.8				1.02	2.87	12.4	2.60	0.713	
Jul	1967	1.06	6.17	8.58		4.35	5.98			3.39	4.36	3.73	2.52	30.3	5.50
Aug	1967	0.599	11.1	1.80		5.08	5.25			4.37	16.7	18.3	10.5	5.77	5.45
Sep	1967	2.64	Discontinued	18.4		7.35	1.54			1.92	2.20	6.14	5.45	2.32	6.47
Oct	1967	10.7		60.9		25.4	18.9	9.58		5.69	5.58	143.9	17.4	4.40	9.58
Nov	1967	2.76		3.59		2.58	2.52	3.47		2.85	1.93	4.38	1.73	1.86	5.81
Dec	1967	5.17		80.3		5.13	4.74	25.7		2.38	2.78	7.76	2.84	3.84	4.68
Jan	1968	5.72		8.26		6.35	5.56	4.89		3.89	3.22	4.35	2.62	4.02	40.1
Feb	1968	5.28		8.20		6.20	6.43	6.06		4.36	5.95	3.96	2.96	2.84	25.9
Mar	1968	7.99		25.2		10.0	6.47	7.45		4.08	4.10	5.84	5.07	4.87	12.7
Apr	1968	93.2		24.8		16.5	46.2	13.9		8.78	4.84	58.1	10.4	45.6	44.1
May	1968	8.64		10.6		15.5	13.1	7.52		5.25	4.67	3.87	20.9	3.86	11.4
Jun	1968	8.93		10.4		9.44	8.31	12.0		4.16	13.3	4.21	4.60	3.55	7.89
Jul	1968	10.1		16.1		17.2	12.3	11.3		6.88	5.28	24.7	6.14	5.25	10.3
Aug	1968	8.86		11.3		10.2	9.04	10.8		5.21	4.54	4.34	5.05	4.41	12.5
Sep	1968	14.5		11.4		10.4	10.3	14.3		7.17	4.90	4.02	5.97	4.46	10.6
Oct	1968	4.12		8.97		3.42	2.78	4.51		1.64	2.63	1.31	2.31	2.12	3.81
Nov	1968	4.55		6.88		4.90	3.48	3.44		1.99	2.28	2.27	2.30	2.18	3.60
Dec	1968	3.27		3.67		2.78	2.95	3.61		1.84	1.84	1.64	2.11	2.32	3.79
Jan	1969	2.87		3.12		2.16	2.64	2.74		1.59	2.04	1.43	1.84	1.82	2.60
Feb	1969	3.23		4.57		2.23	4.11	3.42		1.79	2.16	1.62	1.68	2.20	3.57
Mar	1969	4.54		5.36		3.64	4.65	3.52		2.29	3.14	1.83	2.74	1.95	4.04
Apr	1969	3.75		4.12		2.84	5.35	4.14		1.34	1.80	1.18	1.83	1.93	3.15
May	1969	7.08		4.03		4.57	3.31	3.83		1.69	1.98	1.44	2.17	2.10	4.28
Jun	1969	3.91		8.09		3.02	3.17	3.21		2.21	2.04	1.90	2.59	1.94	3.98

TABLE XV. OPERATIONAL LAPEL SAMPLE SUMMARY

Operation	No. of Samples Within Concentration Range			High Sample Range (ug/m^3)
	<0.5 ug/M^3	0.5-20 ug/M^3	>2.0 ug/M3	
A. Motor Crews				
1. Grid Recovery	138	10	10	2.4 to 18.6
2. Sampler Cleaning	14	8	1	2.4
3. Pad Re-entry	4	2	7	3.0 to 39.0
4. Pad Washdown	1	2	1	2.7
5. Motor Teardown	4	2	5	3.5 to 20.4
B. Welders	5	3	0	
C. Industrial Hygiene Technicians, Pad Post-test	9	1	5	2.9 to 86.5
D. Chemists				
1. Synthesis	10	2	0	
2. Analysis	14	0	0	

measurable airborne resuspension. The majority of the higher concentrations occurred on one recovery run late in the program with results in the 5 to 13 ug/m^3 range. The 18.6 value is thought to be spurious since four other samples taken at the same time under the same conditions were within background.

Sampler cleaning included operations such as removing the used sampler heads from plastic bags, removing the filters, and washing the heads. As expected, these operations did not show appreciable risk of beryllium exposure.

Pad re-entry involved one of the highest risk categories of the program. At times, these personnel would re-enter the pad area some 30 minutes after firing and would take hot throat measurements of the interior nozzle before any washdown was attempted. The results indicate that substantial concentrations of beryllium were present during this operation. Almost all of the high results were in the range of 20 to 40 ug/m^3.

Pad washdown was exactly what the name implies, and the results are generally low, indicating that simple water hosing of the pad efficiently suppressed resuspension of the spent material.

Motor teardown involved the separation of closures from the motor case and removal of the liner from the case, plus steam cleaning and bagging in plastic. These operations had significant potential for exposure but were very well controlled by cleaning and containment of the contaminated parts.

Welding operations included welding and cutting of the motor support stand and chipping on the concrete pad. The results attest to the fact that these surfaces had been effectively decontaminated and did not support aerosol regeneration during these operations.

The industrial hygiene sample results were obtained for sample taking after routine motor firings and for several high-risk re-entries after motor cases had malfunctioned and increased beryllium loading on pad surfaces. The 86.5 result is the highest obtained during the program and was recorded over a 90-minute period by a technician who was taking wipe and soil samples in the pad area. After this incident, exhaust residue was readily discernible on various parts of the pad and surrounding soil. Evidently, considerable quantities of beryllium were resuspended by the soil-sampling procedure. Other personnel samples obtained under the same circumstances ranged from 2.0 to 3.0 ug/m^3.

Analyses of chemical operations indicated quite low amounts, as expected. These operations were carried out in high face velocity hoods equipped with high-efficiency filtration. The results indicate that the hoods were balanced correctly for the operations involved.

OPERATIONAL HIGH-VOLUME SAMPLE RESULTS

A summary of high-volume sample results obtained during various operational situations is shown in Table XVI. These sample situations are generally equivalent to those previously described in detail in the discussion of lapel sample results. Once again, these results do not indicate actual exposure of personnel, but instead indicate the degree of respiratory risk if workers had been unprotected. These samples were obtained using high-volume samplers with membrane filters at flow rates of 12 to 25 cu ft/min, generally, for durations of less than 60 minutes.

The diffusion grid samples were taken from the back of a moving truck during post-test recovery operations. The sample results indicate that even though the turbulent passage of the truck caused swirling clouds of dust, beryllium resuspension from the road network was not an exposure factor.

TABLE XVI. OPERATIONAL HIGH-VOLUME SAMPLE SUMMARY

Location	Operation	Samples	Concentration, $\mu g/m^3$ Average	Range
Diffusion Grid	Servicing samplers	4	0.001	0 to 0.001
Control Room	During test	2	0.007	0 to 0.009
Firing Pad	Re-entry, pre-washdown	28	0.046	0 to 0.740
	Re-entry, post-washdown	66	0.036	0 to 1.70
	Re-entry after motor failure (pre-washdown)	10	0.685	0.027 to 1.77
	Re-entry after motor failure (post-washdown)	2	0.052	0 to 0.104
	Motor teardown	13	0.447	0 to 0.955
	Welding, cutting	11	0.506	0.004 to 2.21
Pad Environmental Shelter	Re-entry, post-washdown	5	0.026	0 to 0.067
Pad Area	General, no operation	34	0.016	0 to 0.141
	East wind	17	0.113	0 to 1.17
Burn Pad	Re-entry, washdown	12	0.014	0 to 0.077
Cleaning House	Cleaning samplers	3	0.006	0 to 0.009
Change Trailer	No operation	6	0.005	0 to 0.016
Toxic Metals Laboratory	Chemical synthesis	16	0.011	0 to 0.092
Chemical Laboratory	Analysis	5	0.003	0 to 0.004

The control room samples were taken inside the blockhouse control room during a firing. There had been some photographic indication that turbulent eddy effects on the exhaust cloud were causing the cloud to migrate slightly upwind toward the blockhouse before it began its diffusion course downrange; however, these samples were essentially background.

The firing pad samples indicated, as expected, that these types of operations afforded the highest risk of airborne exposure. The initial re-entry procedures, for purposes of pad inspection, motor safetying and pad washdown, did not indicate a significant difference between the pre- and post-washdown concentrations; however, after motor failure, the washdown step was very effective in reducing airborne concentrations. The motor teardown operations produced significant average concentrations as expected, but it is somewhat surprising that the highest measured concentration was below 1.0 ug/m^3. Welding and cutting operations on the concrete pad and steel thrust stand surfaces also produced significant average concentrations and nominal excursions above the average.

The two pad area categories illustrate the immediate pad resuspension problems under two types of wind conditions. The general samples were taken with the usual prevailing wind blowing away from the pad toward the downrange area. These samples represent a nonoperational background for the on-pad environment. The east wind samples were taken with strong winds (greater than 15 knots) blowing across the areas of maximum ground deposition toward a sampler located on the pad. These conditions represent the maximum potential resuspension problem. The results show that strong east winds increased the exposure risk by an order of magnitude over the prevailing wind condition.

Burn test operations, which were conducted on a separate pad, were thought to constitute an increased hazard because of lack of directional thrust and lowered cloud buoyancy; however, the burn pad re-entry samples were essentially background.

The last four categories of operations were all adequately controlled by local procedures such as process exhaust ventilation and air filtration.

SOIL SAMPLE RESULTS

Three complete sets of soil contamination data were taken during this program. The first set was taken in February 1963 prior to the first beryllium firing at TA 1-46. An additional set was obtained midway through the ADOBE program when just over 50 percent of the total program propellant had been expended. The final data was obtained in early 1968 after the cessation of beryllium firings.

The analysis results are given in Tables XVII and XVIII. Table XVII is a summary of the mass analyses given in μg/g beryllium of soil (ppm by weight). Sample locations are identified by location on the sampling grid given by arc (distance in meters from the firing pad) and degree radial from the pad (degrees magnetic north). Table XVIII summarizes the surface sample analyses taken as described under Monitoring Program in this section of the report.

The 1963 samples were all analyzed as less than 0.5 μg/g beryllium which was the least detectable limit at that time. These samples were analyzed by the Regional Environmental Health Laboratory, McClellan AFB. Samples were mixed, sieved into greater and less than 325 mesh size fractions, digested in aqua regia and analyzed for beryllium using emission spectrography.

The 1966 samples provided a side-by-side comparison of mass soil and surface soil techniques. The sensitivity of the analysis procedure had been improved to 0.2 μg/g beryllium through the use of smaller dilution ratios. At this point in the program, the closer-in arcs had begun to indicate detectable quantities of beryllium in soil. There were three

TABLE XVII. SOIL SAMPLE RESULTS*

Meter Arc	Degree	February 1963	July 1966	February 1968
0	44			77.6
25	30			30.2
25	44			134
25	60			149
25	76			57.1
25	90			18.1
50	30			2.8
50	44			14.3
50	60			121
50	76			60.6
50	90			7.0
70	16			2.7
75	30			1.9
75	44			27.6
75	60			146
75	76			1.5
75	90			8.0
100	0	<0.5	0.2	0.6
100	16	<0.5	0.2	1.4
100	30	<0.5	0.2	1.5
100	38			10
100	44	<0.5	7.0	32
100	50			41
100	60	<0.5	5.0	96
100	76	<0.5	6.0	4.2
100	88	<0.5		10
150	0	<0.5	0.2	0.7
150	16	<0.5	0.2	0.5
150	30	<0.5	0.2	0.6
150	44	<0.5	1.8	0.6
150	60	<0.5	2.0	0.6
150	76	<0.5	0.5	1.9
150	88	<0.5	0.2	3.2
250	0	<0.5	0.2	0.4
250	16	<0.5	0.2	0.4
250	30	<0.5	0.2	0.3
250	44	<0.5	0.2	0.4
250	60	<0.5	0.2	0.3
250	76	<0.5	0.2	0.2
250	88	<0.5	0.2	0.2
600	0	<0.5	0.2	0.3
600	15	<0.5	0.2	0.4
600	30	<0.5	0.2	0.2
600	45	<0.5		1.7
600	60	<0.5	0.2	0.4
600	75	<0.5	0.2	0.7
600	90	<0.5	0.2	0.3
800	0	<0.5	0.2	0.2
800	15	<0.5	0.2	0.3
800	30	<0.5	0.2	0.2
800	45	<0.5	0.2	0.6
800	60	<0.5	0.2	1.4
800	75	<0.5	0.2	0.2
800	90	<0.5	0.2	0.3
1200	0	<0.5	0.2	0.3
1200	14	<0.5	0.2	0.4
1200	30	<0.5	0.2	0.2
1200	44	<0.5	0.2	0.2
1200	60	<0.5	0.2	0.4
1200	74	<0.5	<0.2	0.2
1200	90	<0.5	0.2	0.1
2400	0	<0.5	<0.2	0.8
2400	15	<0.5	<0.2	0.5
2400	30	<0.5	<0.2	0.5
2400	45	<0.5	<0.2	0.4
2400	60	<0.5	<0.2	1.0
2400	75	<0.5	<0.2	0.9
2400	90	<0.5	<0.2	0.0
4800	0	<0.5		1.0
	14	<0.5		0.8
	30	<0.5		0.8
	46	<0.5		1.0
4800	60	<0.5	<0.2	0.9
4800	74	<0.5	<0.2	0.8
4800	90	<0.5		0.8
9600	0	<0.5	0.2	0.9
9600	14	<0.5	0.2	0.6
9600	30	<0.5	0.2	0.7
9600	44	<0.5	<0.2	0.7
9600	60	<0.5	0.2	0.5
9600	74	<0.5	<0.2	0.8
9600	90	<0.5	0.2	0.6

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* Measured in µg Be/g.

TABLE XVIII. ADHESIVE PAPER SAMPLE RESULTS*

		July 1966		February 1968				
Meter Arc	Degree	Pass 1	Pass 2	Pass 1	Pass 2	Pass 3	Pass 4	Pass 5
0	44			2300	1300	1900	3200	800
25	30			1200	1200	600	800	1700
25	44			300	100	100	100	200
25	60			600	2800	1000	1200	700
25	76			990	1800	840	1000	440
25	90							
50	30			30	30	2.0	2.0	3.0
50	44			40	10	100	4.0	100
50	60			1300	300	700	900	800
50	76			260	490	460	380	1700
50	90			80	130	60	110	70
75	16			50	30	30	40	40
75	30			20	20	30	30	20
75	44			700	200	100	200	200
75	60			900	900	1600	1000	800
75	76			40	40	50	40	50
75	90			90	50	90	100	90
100	0	<0.002	<0.002					
100	16	<0.002	<0.002	10	10	20	20	30
100	30	0.005	0.005	60	20	20	30	30
100	38			70	30	50	60	60
100	44	0.44	0.30	1500	200	300	200	200
100	50			800	1000	500	1400	200
100	60	0.17	0.17	1000	1300	700	1200	1100
100	76	0.013	0.20	30	40	30	60	4.0
100	90			60	60	70	60	80
150	0	0.01	<0.002	8.1	5.8	8.8	9.0	8.7
150	16	<0.002	<0.002	6.9	12.2	10.3	10.2	10.3
150	30	<0.002	<0.002	10.0	9.1	11.5	12.9	15.1
150	44	0.70	0.40	12.5	11.5	12.8	11.7	10.2
150	60	<0.002	<0.002	15.5	13.0	12.5	12.1	13.5
150	76	<0.002	<0.002	24.8	11.4	23.6	33.9	23.7
150	88	0.04	0.012	30.2	36.4	43.5	43.4	56.5
250	0			9.6	8.5	6.7	8.3	11.7
250	16			8.5	10.3	10.7	10.3	10.8
250	30			10.7	11.2	9.0	10.2	10.6
250	44			9.0	8.9	9.3	7.4	5.9
250	60			5.2	7.9	8.1	7.9	8.2
250	76			8.5	6.9	8.8	7.2	7.3
250	88			8.8	8.1	8.5	7.6	6.9
600	0	<0.002	0.05	8.0	8.4	11.2	9.1	7.1
600	14	<0.002	0.01	19.5	13.1	8.7	10.5	7.7
600	30	<0.002	0.009	7.4	7.6	4.7	3.5	3.8
600	45	0.013	<0.002	5.8	11.9	6.8	9.1	13.5
600	60	<0.002	<0.002	22.2	8.9	18.4	20.2	29.1
600	75	<0.002	<0.002	5.1	5.3	4.7	7.1	5.6
600	90	<0.002	<0.002	3.9	2.6	3.5	3.3	3.9
800	0			3.4	8.0	8.5	8.3	7.9
800	14			9.0	12.3	8.9	9.2	6.2
800	30			9.9	9.3	9.2	9.5	10.6
800	45			2.3	4.0	5.1	3.0	4.0
800	60			3.9	11.7	8.3	21.3	29.0
800	75			2.8	5.7	4.1	6.7	8.4
800	90			7.2	5.4	5.3	3.6	5.3
1200	0	0.005	<0.002	4.5	4.6	3.5	3.6	3.7
1200	14	<0.002	<0.002	3.0	4.6	6.2	4.8	5.3
1200	30	<0.002	<0.002	3.8	6.8	6.2	4.8	7.9
1200	44	<0.002	<0.002	17.4	7.1	7.6	6.3	5.9
1200	60	<0.002	0.01	6.3	8.2	12.3	9.4	7.8
1200	75	<0.002	<0.002	6.5	6.1	6.4	5.9	7.5
1200	90	0.003	<0.002	5.6	6.8	4.2	6.8	6.3
2400	0	0.01	<0.002	13.8	32.7	15	10.6	10.9
2400	15	<0.002	<0.002	13.1	11.9	12	21.3	13.5
2400	30	<0.002	<0.002	8.3	10.8	10.9	13.8	21.2
2400	45	<0.002	<0.002	12.3	11.0	11.9	12.3	11.8
2400	60	<0.002	<0.002	11.8	8.4	9.0	8.6	8.1
2400	75	0.013	<0.002	9.4	8.8	7.3	6.9	7.8
2400	90	<0.002	0.002	7.9	7.2	5.0	5.3	10.2
3600	0			8.9	9.6	9.0	9.3	7.5
3600	17			8.8	7.9	7.8	6.6	6.1
3600	30			6.5	7.4	7.0	6.0	7.0
3600	44			7.1	7.2	6.3	5.4	6.4
3600	60			4.0	5.2	5.3	4.2	4.0
3600	74			4.0	4.0	3.8	4.3	5.1
3600	90			5.6	5.2	4.4	6.3	6.6
4800	0			6.8	6.0	5.5	5.2	5.4
4800	14			5.6	4.0	4.4	4.2	5.4
4800	30			8.9	7.2	5.5	7.4	6.0
4800	46			6.6	5.3	10.8	7.0	7.7
4800	60			9.4	8.5	8.4	8.1	8.6
4800	74			8.7	8.0	7.3	7.9	7.8
4800	90			8.1	7.2	8.2	7.4	8.6
9600	0	<0.002	0.003	7.2	8.1	8.9	7.4	6.3
9600	14	<0.002	<0.002	6.4	7.8	7.4	5.0	4.7
9600	30		<0.002	6.5	7.3	14.5	10.9	10.0
9600	44	<0.002	<0.002	9.9	8.1	9.0	6.9	10.8
9600	60	<0.002	0.01	11.2	11.1	9.5	8.6	9.5
9600	74	<0.002	<0.002	10.3	10.2	10.2	10.6	10.1
9600	90	<0.002	<0.002	9.1	8.6	9.3	9.4	8.8

*Measured in micrograms Be/sq ft

positive samples on the 100-meter arc ranging from 5.0 to 7.0 ppm. The 150-meter arc also had three positive samples ranging from 0.5 to 2.0 ppm. The 250-meter arc produced two samples which were barely discernible above background, and all other results out to 9600 meters were less than detectable. Surface samples showed good general agreement with the soil mass analyses although the surface samples indicated small amounts of beryllium out to 9600 meters.

The 1968 sample data is the most extensive of the entire program. This data includes soil mass samples and surface samples from every air sampler location on the diffusion grid. The surface samples were taken in five consecutive passes for this study to see if the beryllium had begun a downward migration.

By the time the program ended, a definite soil fallout pattern had begun to emerge. This pattern is shown in Figure 30 as isoconcentration lines plotted against a log-distance scale to emphasize the results closer to the firing pad. This contour map indicates the relatively minute surface loading resulting from the thousands of pounds of beryllium fired during ADOBE. All of the truly quantitative results occurred within 150 meters from the test stand with the highest results of near 150 ppm located within 75 meters of the firing point. All of the results within 150 meters of the test stand were most probably caused by direct soil impingement rather than fallout. There are a few locations further downwind which indicated slightly above background which could have resulted from particulate fallout. The remainder of the grid was essentially within background for the analysis employed.

Once again, the surface sample analyses indicate good agreement with the mass analyses despite the obvious problems of soil size inconsistencies. The surface samples gave quantitative results out to the 100-meter arc with locations further out generally indicating within background. The use of successive passes proved very inconsistent and did not indicate any noticeable migration trend through soil.

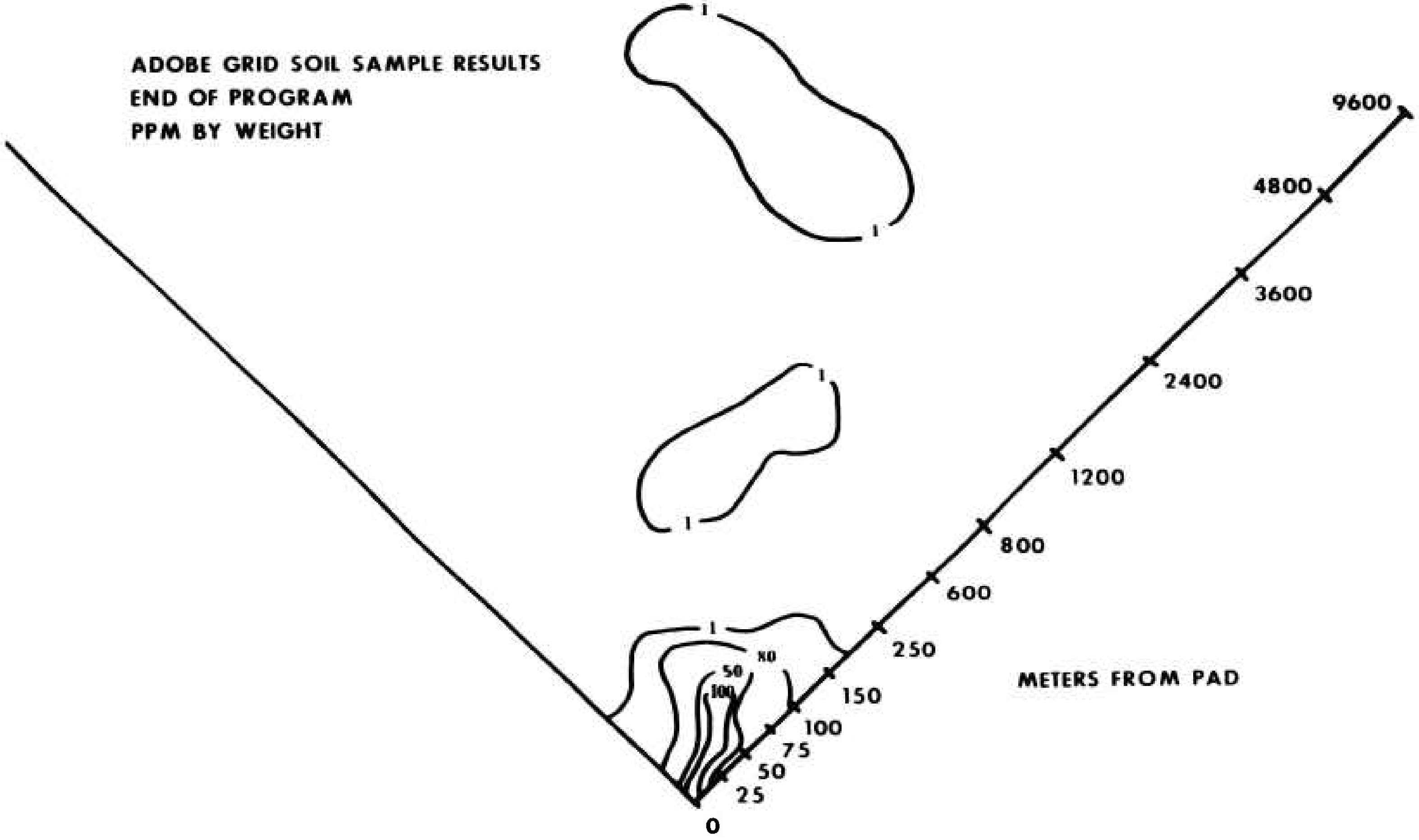

Figure 30. ADOBE Grid Soil Sample Results, End of Program, ppm by Weight

Figure 30. ADOBE Grid Soil Sample Results, End of Program, ppm by Weight

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Mr. Malone graduated from Wittenberg University in 1950 with a degree in chemistry. He worked as a propellant research chemist at Wright-Patterson AFB prior to his arrival at the Air Force Rocket Propulsion Laboratory in 1959. He began work on meteorological diffusion programs in 1963 and since then has continued efforts in related areas. In 1968, he was the first recipient of an Air Force Systems Command Research and Study Fellowship. Mr. Malone studied chemistry at the University of Edinburgh, Scotland, receiving an M.S. degree. He has presented and published over 40 technical papers and has written a book on the analytical chemistry of hydrazine functional groups. Mr. Malone is presently Chief of the Environmental Chemistry Group at AFRPL.