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(VOLUME 1)

Operation

ROLLER COASTER

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Interim Summary Report (U)

DO NOT DESTROY

J. L. Dick, Lt Col, USAF, Research Group Director
Headquarters, Defense Atomic Support Agency
Washington, D.C.

J.D. Shreve, Scientific Director
Sandia Corporation
Albuquerque, New Mexico

J.S. Iveson, Lt Col, UK, Deputy Scientific Director
Atomic Weapons Research Establishment
Aldermaston, England

September 1963

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DEPARTMENT OF DEFENSE
WASHINGTON 25, D.C.

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FOREWORD

Operation Roller Coaster can be considered a continuation of Projects 56 and 57, Operation Plumbbob, both of which were initial attempts to define the problems associated with scattered plutonium. Although these projects provided a wealth of valuable data, the very uniqueness and complexity of the problem made it impossible to foresee all the data requirements and parameters requiring field study. As a result, some critical data points were questionable when applied to operational situations.

As a result of the complexity of Operation Roller Coaster and of the necessity to coordinate the results of the various events, the organization of this report is somewhat different from that ordinarily associated with weapons tests reports. The format used presents each event as an integrated effort, as it was accomplished in the field, using the individual project contributions as required to present data, results, and conclusions in the least voluminous manner. Each project report is provided as an appendix, thus expanding the details of each part of the entire project.

Volume 1 contains overall results from Operation Roller Coaster, and Volume 2 contains individual reports from all projects which participated in the operation.

ABSTRACT

Operation Roller Coaster, carried out in the western sector of the Las Vegas Bombing and Gunnery Range with joint US/UK participation, was a research program devoted to the study of non-nuclear explosions of plutonium-bearing devices in different environs. The principal and several objectives were to investigate by exposure of animals to precisely measured aerosols the biological hazard of plutonium scattered by non-nuclear explosions, to evaluate the effectiveness of earth covered storage structures in reducing the radiological hazard produced by a detonation within the structure, and to improve mathematical cloud models by which to forecast the areal extent of plutonium dispersed, and the magnitude of radiological exposure likely from any given accident situation. Four shots, called DOUBLE TRACKS and CLEAN SLATE Nos. 1, 2 and 3 were fired.

Three species of animals (dogs, sheep, and burros) were exposed to measurable air concentrations of plutonium. On site, physical instrumentation comprised surface and air collections over areas which varied shot to shot from about 9 to 70 square miles. On three of the four shots, a large balloon-supported vertical air sampling array was operated to attempt direct quantification and characterization of plutonium in the cloud. Quite detailed micro-meteorological data were collected as well.

Postshot surface activity measurements with alpha and gamma survey instruments and with a gamma spectrometer (vehicle-mounted) gave gross estimates of plutonium accountancy. Within that portion of the $1 \mu g/M^2$ contour contained in the instrumented array (variable from 9 to 65 sq. mi.) integrations gave the following: 206g on DOUBLE TRACKS, 65g on CLEAN SLATE No.1, 275g on No.2 and 202g on No.3. Field laboratory counting of collected deposition panchets gave similar answers. Field counting of air sampler stages was done also; these rough data show the variation in total and nominal respirable plutonium collected as a function of field position.

The results of this series of experiments should serve as a basis for agreement between the United States and the United Kingdom on mutual standards for the storage, transport, and handling of plutonium-bearing weapons.

PREFACE

The work and enthusiasm of the Referee Team for Radiochemical Analysis are warmly acknowledged. Their careful preparation of bidding specifications, evaluation of contract proposals, confirmatory analysis of qualification samples, and agreement to prepare spikes during the long foreseen analytical work were major contributions to Roller Coaster.

The Operation Roller Coaster staff acknowledges the invaluable contributions made to the scientific effort by members of the following military organizations:

UNITED STATES ARMY

502nd Chemical Co., Fort Bragg, North Carolina
USA Dispensary, Ft Sam Houston, Texas
27th Ord Det, Tooele Army Depot, Tooele, Utah
Hq Troop Command, Ft McPherson, Georgia
Medical Research Institute, Bethesda, Maryland
Hq 5th USA Army Vet Food Insp Sv, Chicago, Illinois
Fort McArthur, San Pedro, California
U.S. Army, Ft Meade, Maryland
XVIII Abn Corps and Ft Bragg, North Carolina
27th Ord DGT (ED), Ft McArthur, California
53d Trans Co, Ft Irwin, California
Armed Forces Institute of Pathology, Washington, D.C.
58th Ord DET (ED), Ft McArthur, California
50th CI Det, Ft Polk, Lousiana
1st Army Vet Food Insp Unit, 346 Broadway, New York City, New York
Ft Lewis, Washington
101st Abn Div and Ft Campbell, Kentucky
Hq Dt, USAH, Ft Sill, Oklahoma
3rd USA Element, Memphis Army Depot, Memphis, Tennessee
24th Chemical Co., Ft Bragg, North Carolina
USATC Inf, Fort Dix, New Jersey
USA Garrison, Boston Army Base, Massachusetts
USA Hosp, Ft Leonard Wood, Missouri
Walter Reed Army Medical Center, Washington, D.C.
Hq 6th Army, Presidio of San Francisco, California
170th Ord DET (ED), Ft Lewis, Washington
Hq USA Hosp Ft Hood, Texas
Patterson Army Hosp, Ft Monmouth, New Jersey
84th Chemical Co., Ft Bragg, North Carolina
Ft Belvoir, Virginia (USAEC and FB)
1352d Photo Gp, LmL, Los Angeles, California
USASCC, Arlington Hall Sta, Arlington, Virginia
USA Engr Center, Ft Belvoir, Virginia

Hq, Ft Sheridan, Illinois
Dugway Proving Ground, Dugway, Utah
502d MP Co, 2d AD, Ft Hood, Texas
USA Armor and Arty Firing Center, Ft Stewart, Georgia
1st Ord Co. GAS, Ft Chaffee, Arkansas

UNITED STATES AIR FORCE

8648th AF Recovery Gp Reserve, Alameda, California
6th Weather Sq, Tinker AFB, Oklahoma
USAF School of Aerospace Med, Brooks AFB, Texas
4900th USAF Dispensary, Kirtland AFB, New Mexico
AFMDC (ARSV) Holloman AFB, New Mexico
Hq. AF Logistical Command, WPAFB, Ohio
6571st Aeromedical Rsch Lab, Holloman AFB, New Mexico
6570th AMRL, WPAFB, Ohio
6550th Support Wg, Patrick AFB, Florida
Med Sq Section, USAF Hosp, Eglin AFB, Florida
Hq AFSC, Andrews AFB, Washington, D.C.
Dugway Proving Ground, Dugway, Utah
Brooks AFB Hosp, San Antonio, Texas
Hq Trp 1st Recon Sq, 15th Cav 2d AD, Ft Hood, Texas

UNITED STATES NAVY

Naval Const Bn Center, Port Hueneme, California
ComCB LANT, Davisville, Rhode Island
USN Missile Facility, Pt Arguello, California
Navy Medical Center, Bethesda, Maryland
Navy Hosp, St Albans, Long Island, New York

Selected and specially trained military personnel collected from all sections of the United States and the United Kingdom were integrated directly into the scientific Project Agencies and comprised more than one-half of the assigned strength within the total effort. The quiet, efficient, and professional manner in which this military-civilian team carried out all phases of the scientific effort to achieve the outstanding success evident in Roller Coaster is a tribute to each man and the service he represented.

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TABLES

FIGURES

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

With the advent of the manufacture of plutonium at Hanford in 1944, concern for its biological effect was foremost in the minds of individuals responsible for the health and safety of personnel working with the material. Physical and biomedical programs were carried out and, subsequently, radiological standards in the form of maximum permissible levels (MPL) were established for body organs considered critical and of maximum permissible concentrations (MPC) in air and drinking water.

Plutonium is an alpha emitter and therefore constitutes an internal hazard only. It can enter the body via ingestion, inhalation, or through cuts or abrasions. The mode of entry into the body of greatest concern is by inhalation, since past research programs have indicated that the uptake of plutonium by the gastrointestinal (GI) tract or by wounds is small. Any particle small enough to reach the lower respiratory tract has an excellent chance of adhering to alveolar surfaces and causing local radiation damage. The rate of removal is low and is considered to have a biological half-life of about one year. Some of the particulate matter so captured may, if locally soluble (even otherwise perhaps), be transferred directly into the blood stream over a period of several days. Any nominally insoluble material so transferred stays as blood burden until its trace solubility allows eventual assimilation to the extent of some 70 percent of the material carried. This 70 percent is believed to be distributed principally in the bone, where it remains indefinitely, as far as the human lifespan is concerned. There is also evidence that particles in the lung are taken up by phagocytes and are deposited in the hylar lymph nodes.

The development of plutonium-bearing weapons of modern design has created a situation wherein potential accident conditions exist in conjunction with transportion, storage, and operational readiness, which could subject not only research and industrial workers but also localized segments of the general public to some degree of plutonium exposure. This condition could result if the device accidentally burned or were accidentally detonated. Extensive safety studies conducted in conjunction with the design of new-type weapons demonstrated that the destruction would be entirely non-nuclear. Evidence gathered from other tests (especially by the UK) and accidents that have occurred indicates that problems associated with burning weapons are much less serious than those associated with a detonation.

The first tests to determine estimates of the plutonium contamination problem were carried out at the Nevada Test Site (NTS) in November 1955 and January 1956. These studies were followed by a second field experimental program known as Project 57, Operation Plumbbob. This was accomplished in April 1957.

The results of these studies were used as a basis for storage and transportation criteria of plutonium-bearing weapons throughout the United States. However, when overseas storage sites were established, population densities in the vicinity of the sites were on the average considerably greater than in this country. Further, acute levels of air concentration deemed permissible in the UK were somewhat more restrictive and additional delineation of the exposure problem appeared necessary. These factors led to a meeting on 12 July 1962 of representatives of the United Kingdom, the U. S. Atomic Energy Commission, and the U. S. Department of Defense. This meeting resulted in the formulation of a paper entitled "Concepts and Objectives of Proposed Plutonium Scattering Tests" in which the basic objective was, "to investigate the biological hazard of scattered plutonium and to evaluate the plutonium-scavenging effects of the earth-covered storage structures." This paper was used to formulate the field test plan for Operation Roller Coaster.

1.2 OBJECTIVES

The objectives of the research program were:

(1) To obtain, by physical and biological measurements, necessary data on the plutonium airborne particulate to permit an assessment of the acute (inhalation) hazard.

(2) To measure the distribution of plutonium on the ground to permit detailed accountability of the amount involved in the field of measurement.

(3) To evaluate the total effectiveness of the structures, including varying thicknesses of earth cover for reducing the radiological hazard from a real accident.

(4) To obtain those data of special importance in forecasting the hazard arising from a real accident (cloud models).

1.3 ORGANIZATION

Operation Roller Coaster was a joint U. S. Atomic Energy Commission, U. S. Department of Defense, United Kingdom Atomic Energy Authority (AEC/DOD/UK) research program. The detailed organizational structure is shown in Figure 1.1. Key personnel selected were:

Research Group Director: Lt Col James L. Dick, USAF
Scientific Director: Dr. James D. Shreve, Sandia Corporation
Deputy Scientific Director: Lt Col J. Stuart Iveson, AWRE/UKAEA*
ALOO Coordinator: Mr. Everett R. Mathews
CHDASA Program Advisor: Lt Col Jack C. Bentley
Scientific Planning and Policy Group:
Dr. Gordon Dunning, DOS/AEC
Dr. William Otting, Hq/DASA
Dr. Kenneth Stewart, AWRE/UKAEA

As this was a joint program with the United Kingdom, its representatives were considered an integral part of the scientific team. The UK was represented by 14 personnel who were integrated into the field activities. Subsequently, UK laboratory personnel are to perform a portion of the chemical analyses and participate in the evaluation and interpretation of the experimental results.

*Atomic Weapons Research Establishment, United Kingdom Atomic Energy Authority (AWRE, UKAEA).

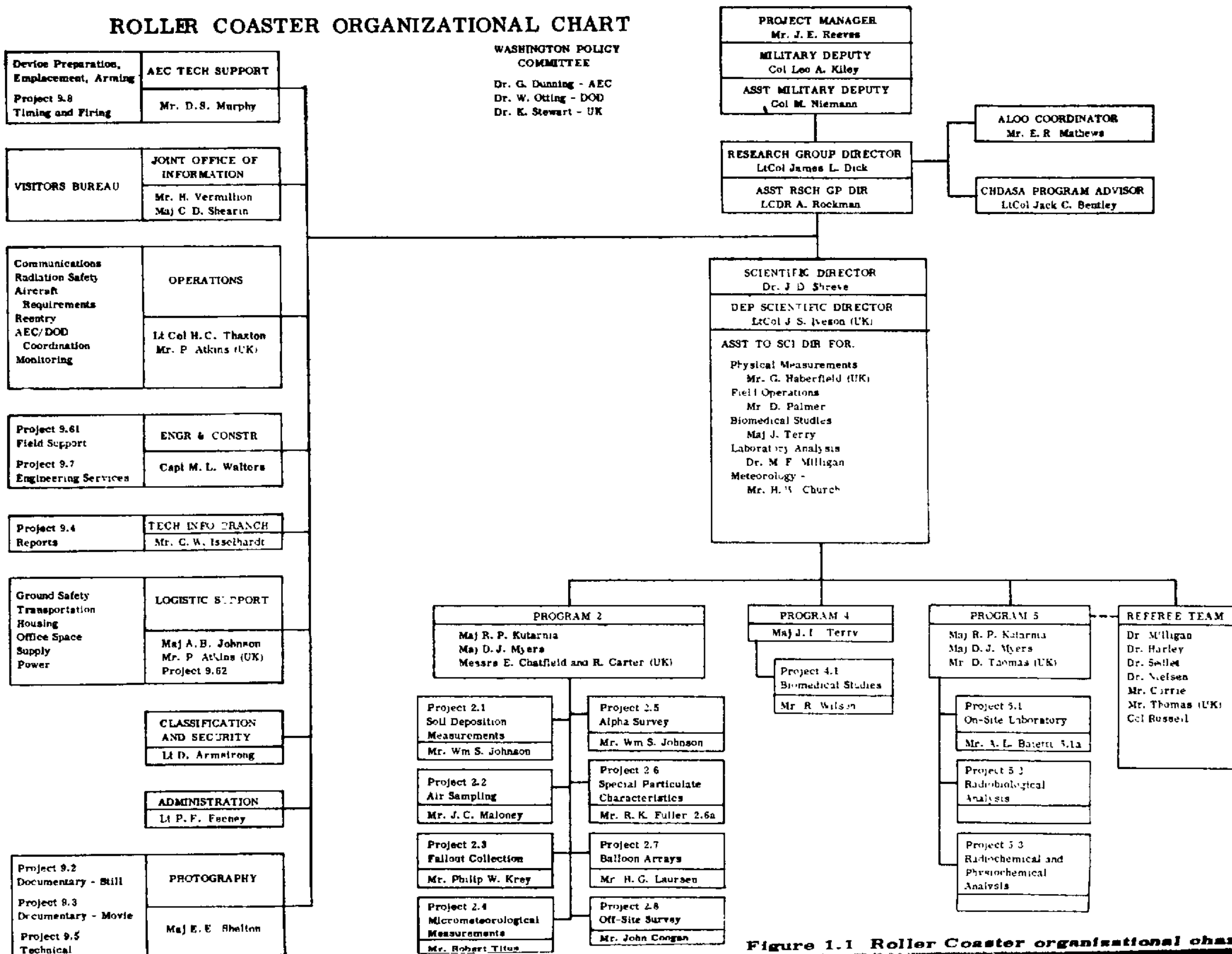


Figure 1.1 Roller Coaster organizational chart.

CHAPTER 2

DESCRIPTION OF EXPERIMENT

2.1 LOCATIONS

Operation Roller Coaster was conducted on a portion of the Las Vegas Bombing and Gunnery Range and Sandia Corporation's Tonopah Test Range (TTR) in southwestern Nevada. The basic criterion for site selection was a relatively flat area fairly remote from populated areas. Four tests were planned: DOUBLE TRACKS and CLEAN SLATE No. 1, No. 2, and No. 3.

Three shot points were chosen in Cactus Flat and one in Stonewall Flat, approximately 20 miles east of Goldfield, Nevada. The approximate test area in Stonewall Flat stretched from 37°33'N to 37°50'N and from 116°46'W to 117°05.5'W in which ground zero for DOUBLE TRACKS was set at 37°42'22.53"N; 116°59'14.23"W. The inclusive coordinates bounding the Cactus Flat area used were 37°33'N to 37°50'N and 116°30'W to 116°46'W with three ground zeros identified as follows: CLEAN SLATE No. 1, 37°42'30.92"N; 116°39'25.09"W; CLEAN SLATE No. 2, 37°45'40.43"N; 116°36'48.58"W; and CLEAN SLATE No. 3, 37°45'33.22"N; 116°40'48.88"W. The relative locations, grid area coverage, and orientations are shown in Figure 2.1.

2.2 EXPERIMENT MOTIVATIONS AND DESIGNS

2.2.1 DOUBLE TRACKS. The DOUBLE TRACKS event was a research study designed to investigate the characteristics of the plutonium-bearing particulate material, formed from a one-point detonation of a device located one foot above a steel-faced concrete surface. The study required elaborate measurements, throughout the field, of the duration and intensity of aerosolized plutonium during its diffusion and settling from the detonation cloud. The corresponding ground deposition pattern was a major interest as well. Finally, DOUBLE TRACKS had the additional special intent of exposing animals and air samplers to the same respirable concentrations of plutonium and uranium. Thus, the aerosol particle size spectrum, its immediate transport and fallout and its biological uptake, original body deposition, metabolism and eventual sites of retention were all principal aims of this event.

In the field pursuit of these aims, an extensive array of ground and balloon-borne air samples, fallout collectors, overlapping stations for three species of animals (burros, sheep, and dogs) and special instruments extended more than 9 miles downwind over a 90-degree sector and encompassed an area of about 70 square miles. Stations and instrument positioning on the arrays are indicated in Figures 2.2 through 2.5. Many features of the sampling arrays were movable up to one hour before shot time; certain others were manned and mobile through the period of cloud passage. Vertical curtains of sampling instrumentation, supported by large balloons, were placed in the downwind grid. These too were capable of being moved to assist in interception of the cloud (Figures 2.6 and 2.7).

<u>2.2.2 CLEAN SLATE</u>. The three CLEAN SLATE shots were designed to contrast weapons accidents, with respect to hazard per unit plutonium mass contained, for conditions of open storage, storage in a DASA igloo with 2 feet of earth cover, and storage in a proposed DASA igloo with 8 feet of earth cover (Figures 2.8 and 2.10). By U. S. storage criteria, the maximum quantity of plutonium permitted in a standard igloo is twice that allowed for open storage. Yet no satisfactory test data certification of this ruling has ever been made.

In CLEAN SLATE No. 1, nine devices were detonated in sequence to simulate normal propagation (Figure 2.9). Extensive physical measurements were made throughout the array as shown in Figure 2.2 except that the array was shortened in length to 35,000 feet (Figure 2.1).

The hazard moderation by earth cover was measured in two experiments conducted in igloos covered by 8 feet (CLEAN SLATE No. 3) and 2 feet (CLEAN SLATE No. 2) of earth, respectively.

Figure 2.8 is a representation of the CLEAN SLATE No. 3 igloo, showing two compartments, one of which was instrumented for blast effects. The CLEAN SLATE No. 2 igloo consisted of a single compartment. Each igloo contained 19 devices (Figure 2.10). One device in each igloo contained plutonium. The arrays for CLEAN SLATE Nos. 2 and 3 were approximately 3 miles in length and 3 miles wide at the distant arc (Figure 2.1), with instrumentation and layout similar to that shown in Figure 2.2.

Limited extent of all arrays was a practical matter; clearly, some activity would travel farther downwind in all cases. Off-site, this contingency was met through measurements by the United States Public Health Service (USPHS). Since extra instruments and time were available on CLEAN SLATE No. 3, additional remote stations were activated. Balloon curtains were also used in all CLEAN SLATE events except in CLEAN SLATE No. 3, when no large balloons were available.

2.3 WEAPONS REQUIREMENTS AND MODIFICATIONS

The following devices, modified as indicated, were used:

2.3.1 DOUBLE TRACKS. One device was contained in an aluminum case and made suitable for one-point detonation at one of three preidentified detonator wells. All oralloy was removed and replaced with depletalloy of similar mass and configuration. The device did not contain any form of initiation system.

2.3.2 CLEAN SLATE. Each of the two igloo events (CLEAN SLATE Nos. 2 and 3) required a total of 19 devices. One device in each shot contained plutonium, the other 18 contained depletalloy. The total mass content in each was equivalent to that contained in an unmodified device.

The open storage event required one device, modified as outlined in Section 2.3.1, and eight HE spheres, modified as outlined for the igloo events. No device contained any type of initiation system. Details of the device design are contained in Reference 1.

2.4 SAFETY PROCEDURES

Dedudding operations were deemed advisable and accomplished for both Stonewall Flat and Cactus Flat. Both of the intended work areas were used formerly as gunnery and bombing ranges. All identifiable HE hazards, as well as scrap metal bombs, were removed.

It was anticipated that the concentration of plutonium distributed beyond the site and adjacent government land would not be hazardous. Even so, decision to fire each shot included a specific evaluation of off-site contamination in light of shot time meteorology. The devices used in the program were modified to insure no nuclear yield.

An extensive Rad-Safe plan was prepared for all events, covering criteria of dress, protective equipment, respiratory devices, contamination levels, and procedures. This plan treated preshot training, operational aspects of Rad-Safe, monitoring, postshot environmental health, decontamination, and off-site safety. The Rad-Safe policy was based on a philosophy of the absolute minimum exposure consistent with operational success; in no case was an exposure in excess of present industrial standards anticipated. The details of the radiological safety plan are contained in Appendix A.

Other safety aspects such as vehicle operation, fire regulations, industrial safety, and medical aid were established in consonance with presently accepted standards and, in some cases, made more rigid because of unusual operations.

Following the completion of the operation, adequate decontamination and/or reclamation of the area was accomplished.

2.5 CONTROL POINT

A special control point was established to provide a center for the rigid control of the diverse operations. The CP consisted of trailers which could be quickly redeployed between events. The general layout appears as Figure 2.11.

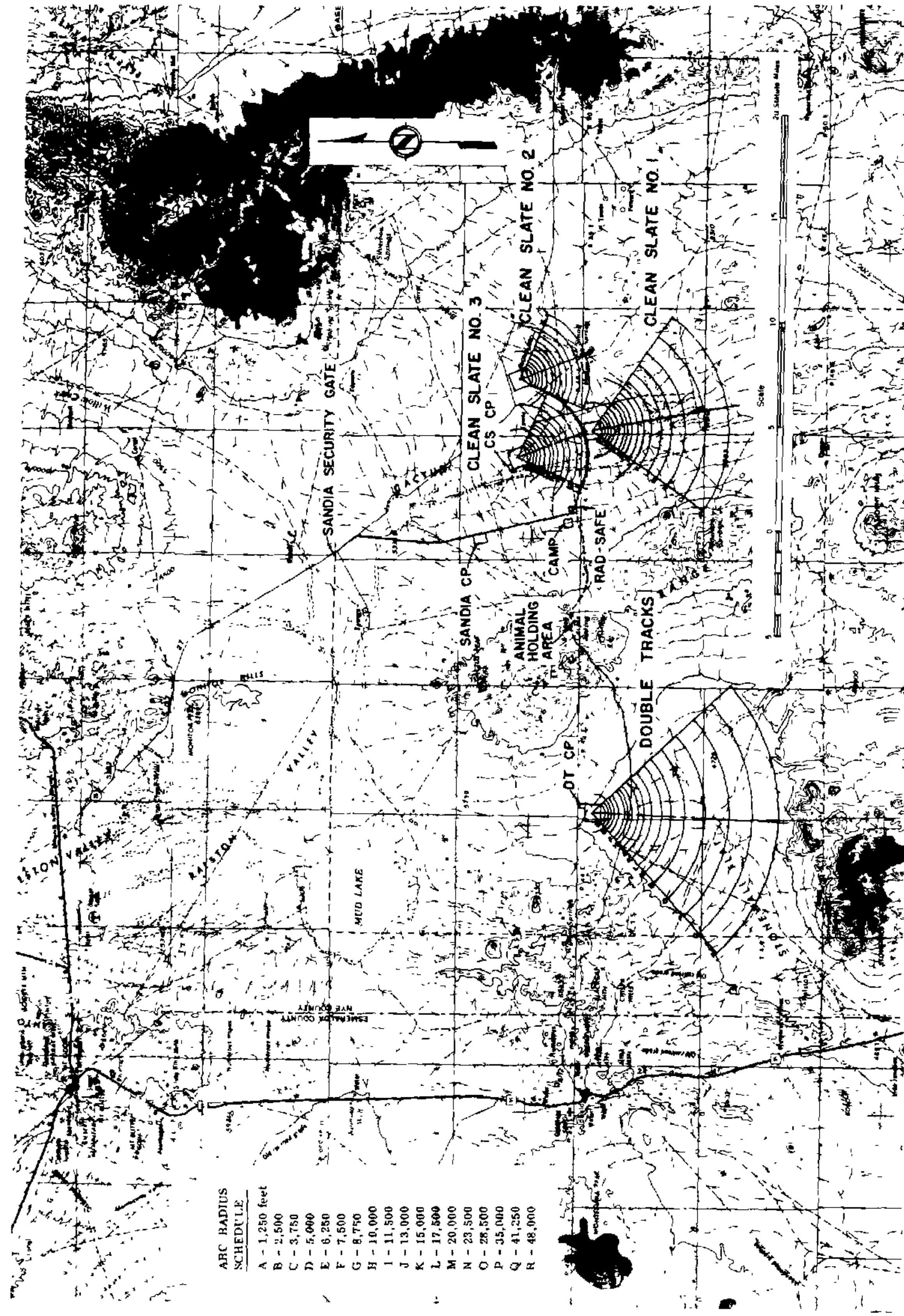
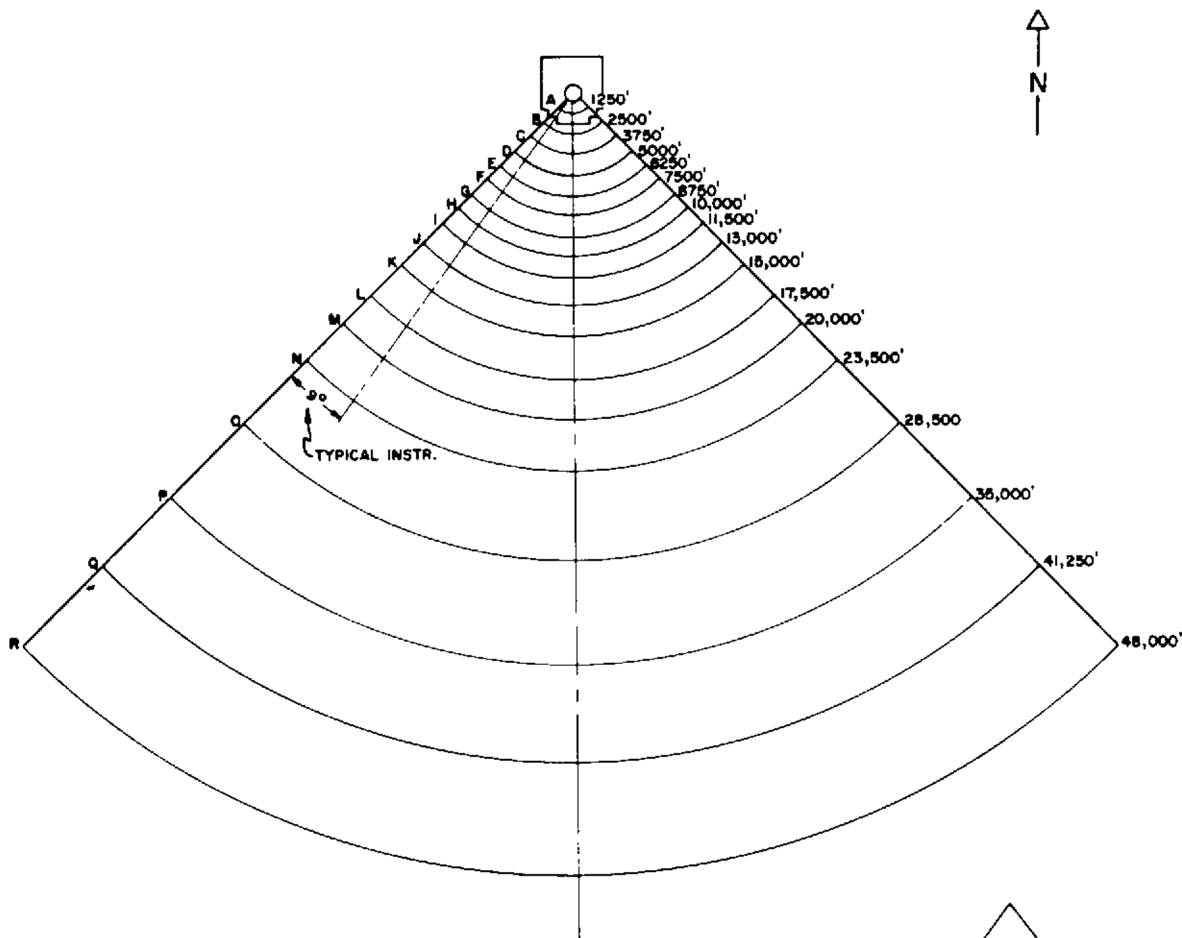
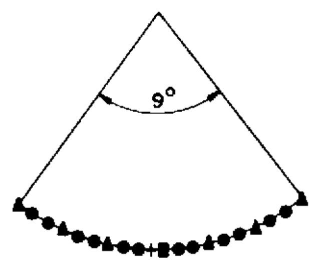


Figure 2.1 Roller Coaster site plan.



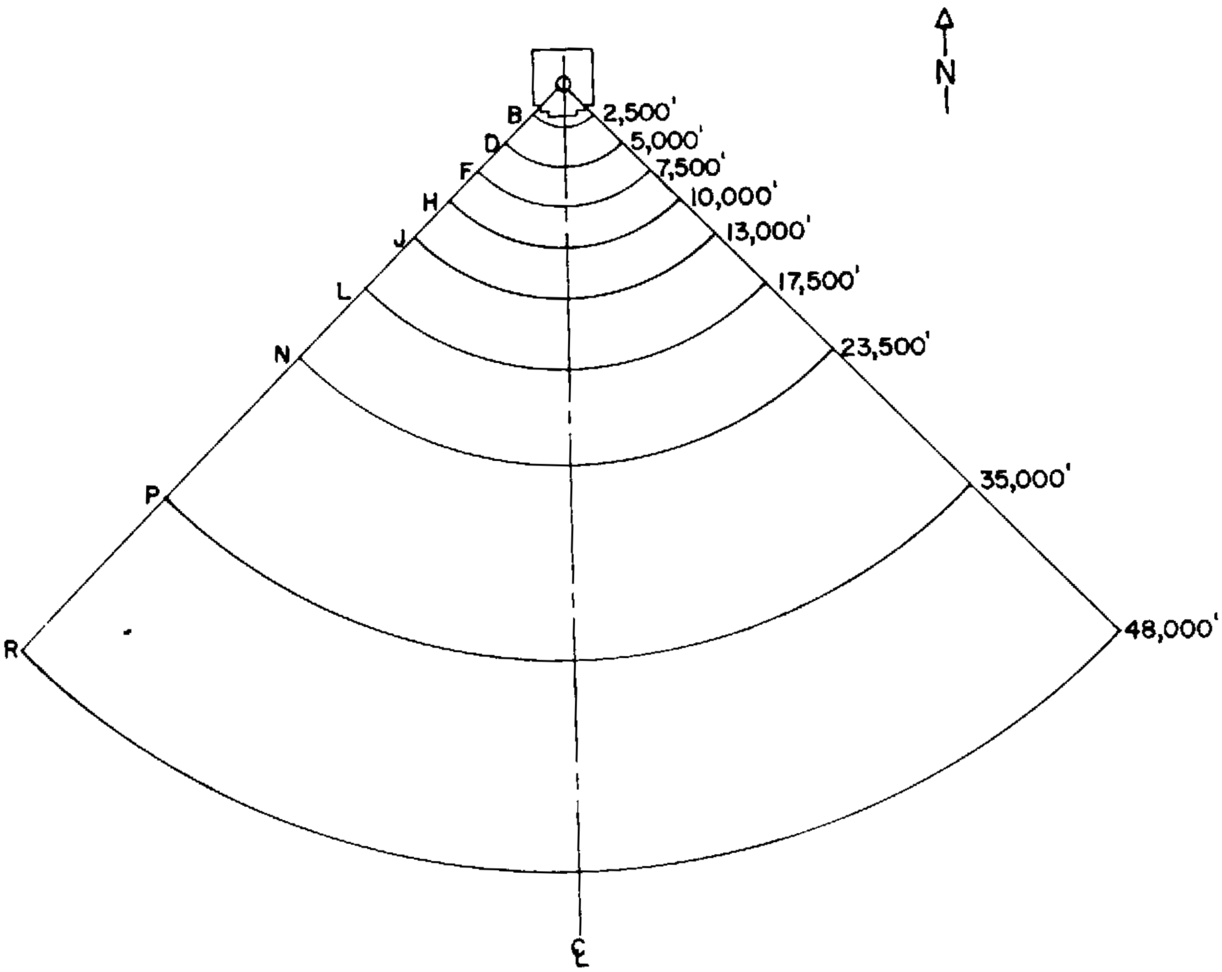
INSTRUMENTATION

- ● 2560 α SURVEY PADS – 121 PER ARC ¾° APART
- ▲ 622 INTEGRAL FALLOUT COLLECTORS – 61 PER ARC 1½° APART
- + 78 TOTAL AIR SAMPLERS – 6 PER ARC
- ▮ 57 CASCADE IMPACTORS – 4 PER ARC



TYPICAL INSTR AT ARC-N

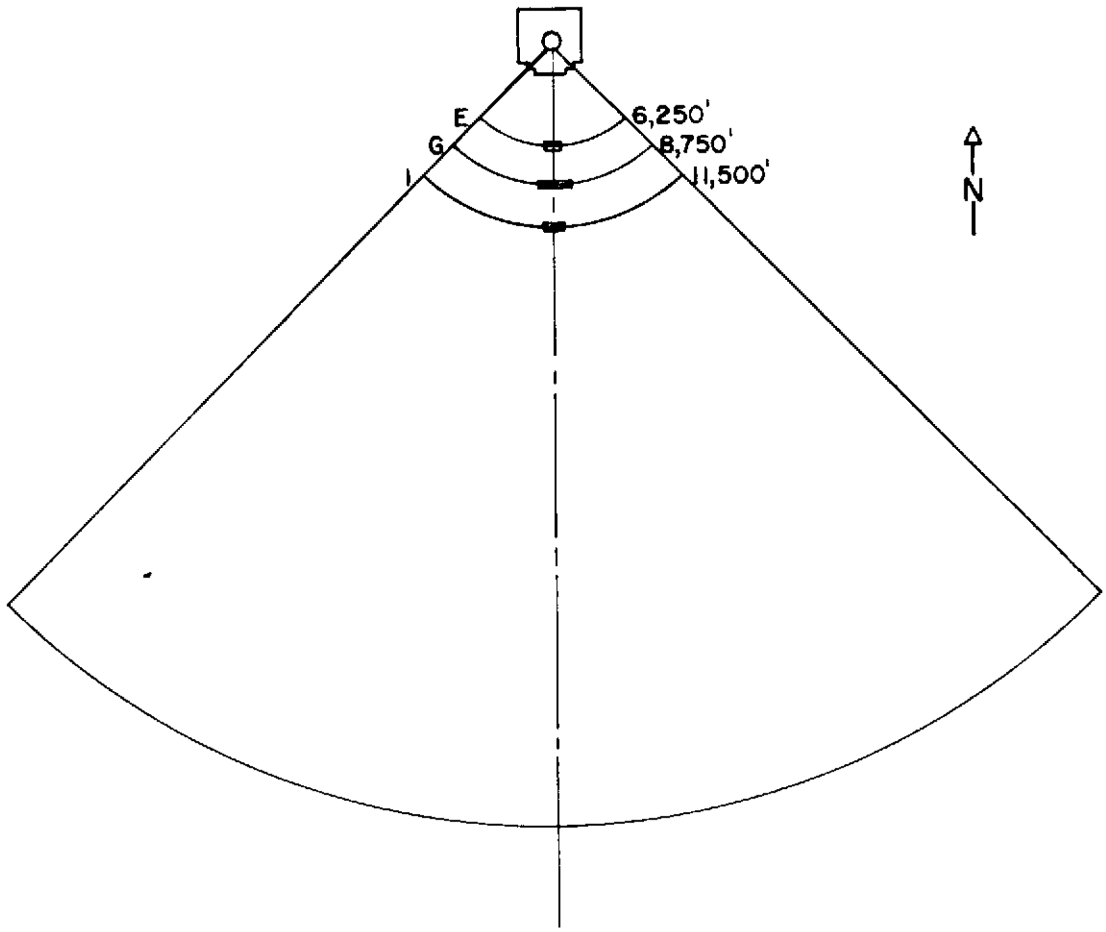
Figure 2.2 Fixed ground instrument array for DOUBLE TRACKS. (Maximum array used.)



NOTES:

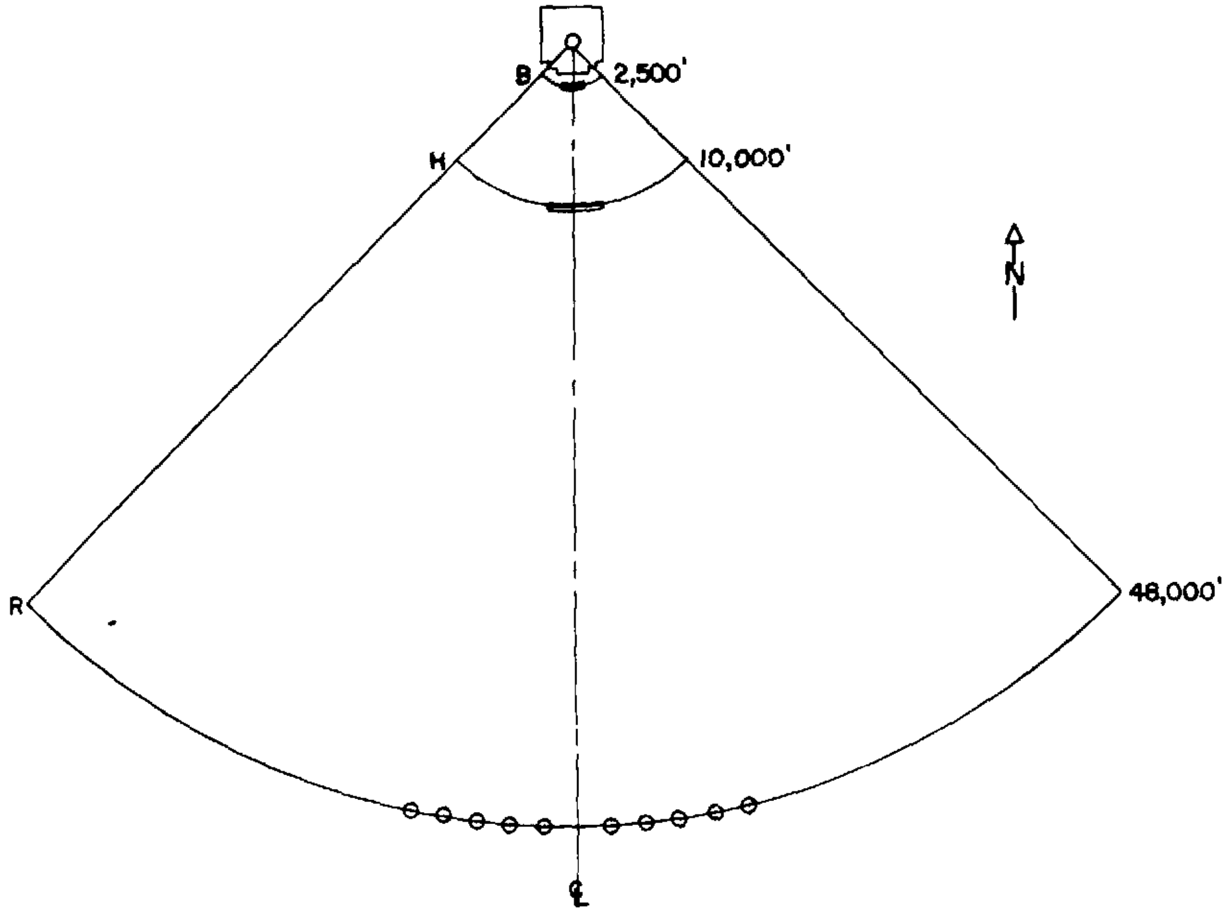
1. DESIGNATED ARCS CONTAIN 11 TOTAL AIR SAMPLERS AND 20 CASCADE IMPACTORS
2. TOTAL INSTRUMENTATION-99 TOTAL AIR SAMPLERS AND 180 CASCADE IMPACTORS
3. SAMPLERS SPACED $1\frac{1}{2}^{\circ}$ APART
4. ADDITIONAL INSTRUMENTATION
   ARC F-SEQUENTIAL AIR SAMPLERS-10
   ARC L-SEQUENTIAL FALLOUT COLLECTORS-11

Figure 2.3 Movable instrumentation array for DOUBLE TRACKS.



ARC	ANIMALS
E	24 BURROS 36 SHEEP 24 DOGS
G	36 BURROS 60 SHEEP 42 DOGS
I	24 BURROS 36 SHEEP 24 DOGS

Figure 2.4 Animals and their nominal field positions.



ARC	INSTRUMENTATION
B	60 CASCADE IMPACTORS 33 TOTAL AIR SAMPLERS 744 STICKY CYLINDERS 18 STICKY PLATES
H	44 TOTAL AIR SAMPLERS 165 STICKY CYLINDERS
R	16 CASCADE IMPACTORS 200 STICKY CYLINDERS

Figure 2.5 Nominal balloon array positions and intended instrumentation.

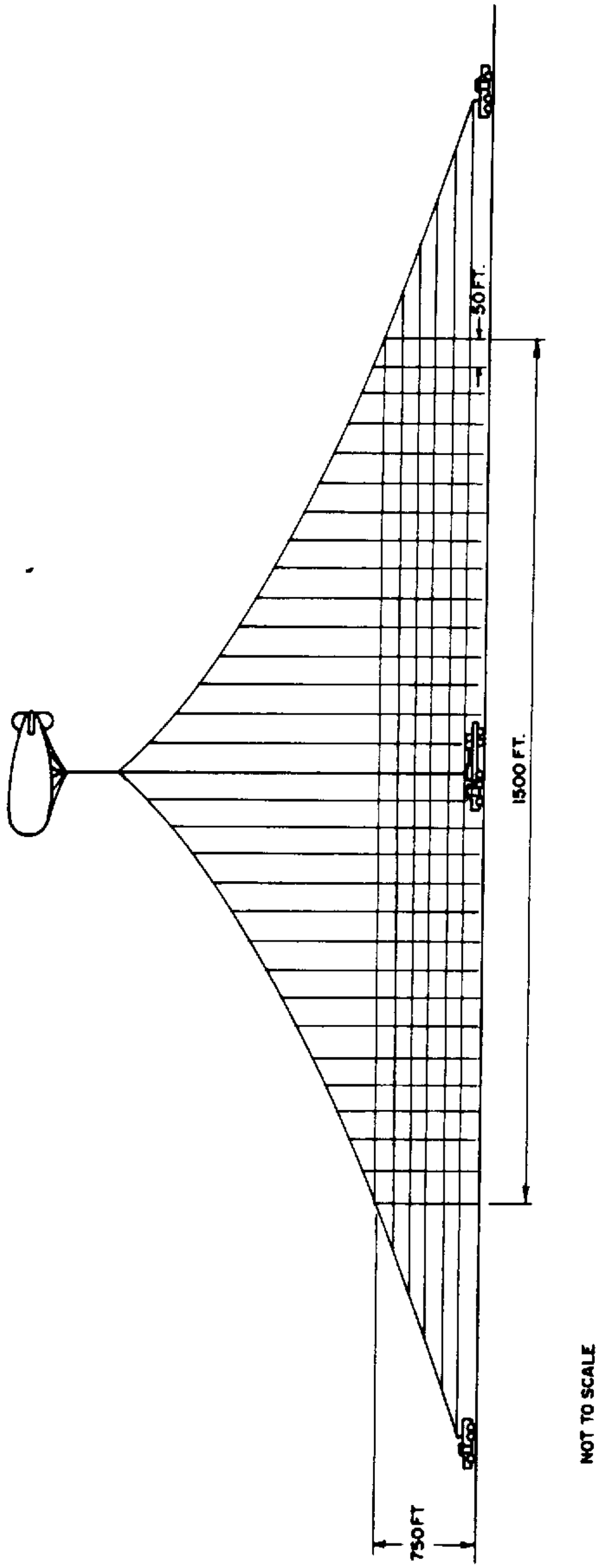


Figure 2.6 Sketch of first balloon curtain.

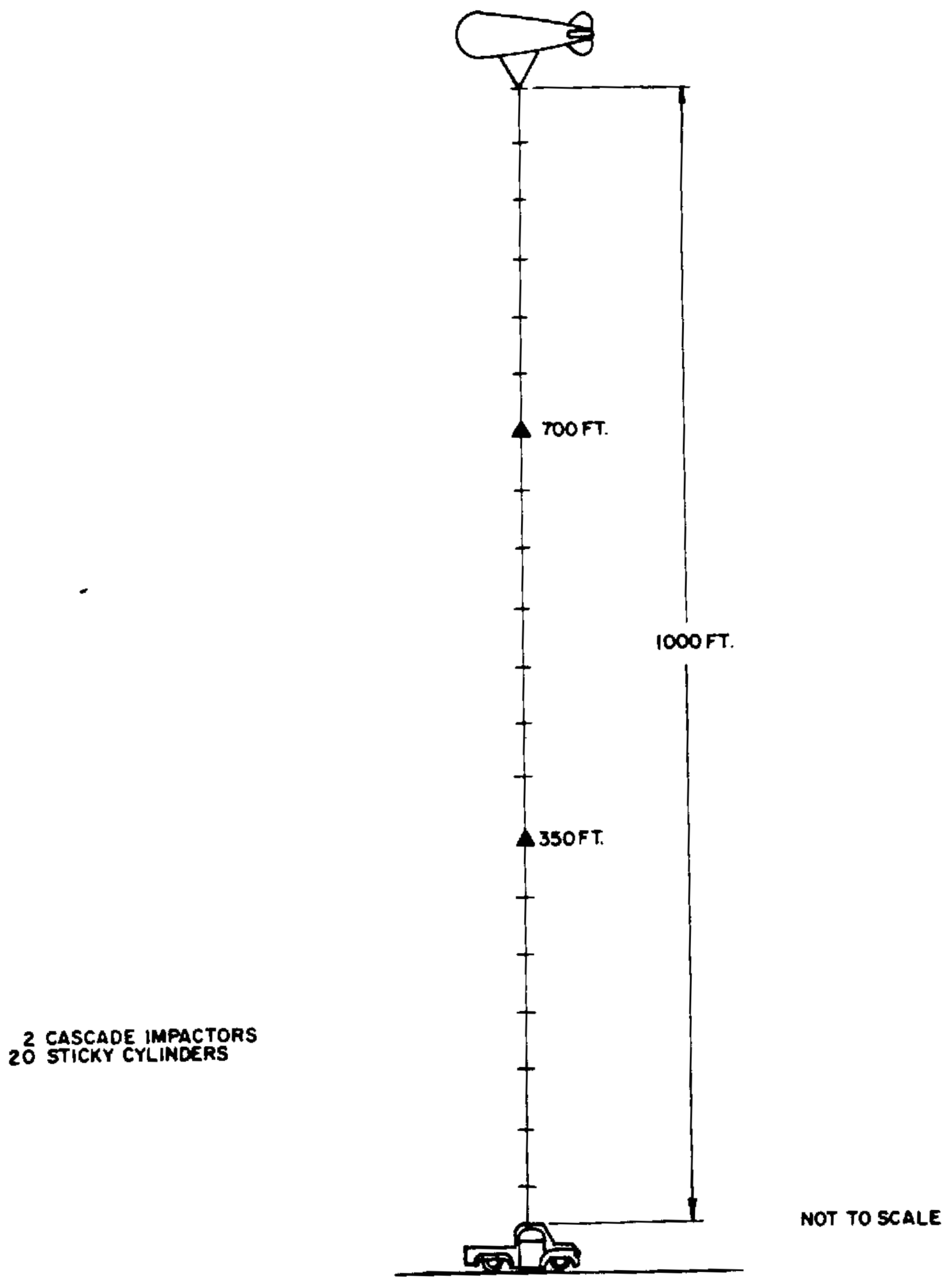


Figure 2.7 Typical instrumentation of intended Arc R balloons.

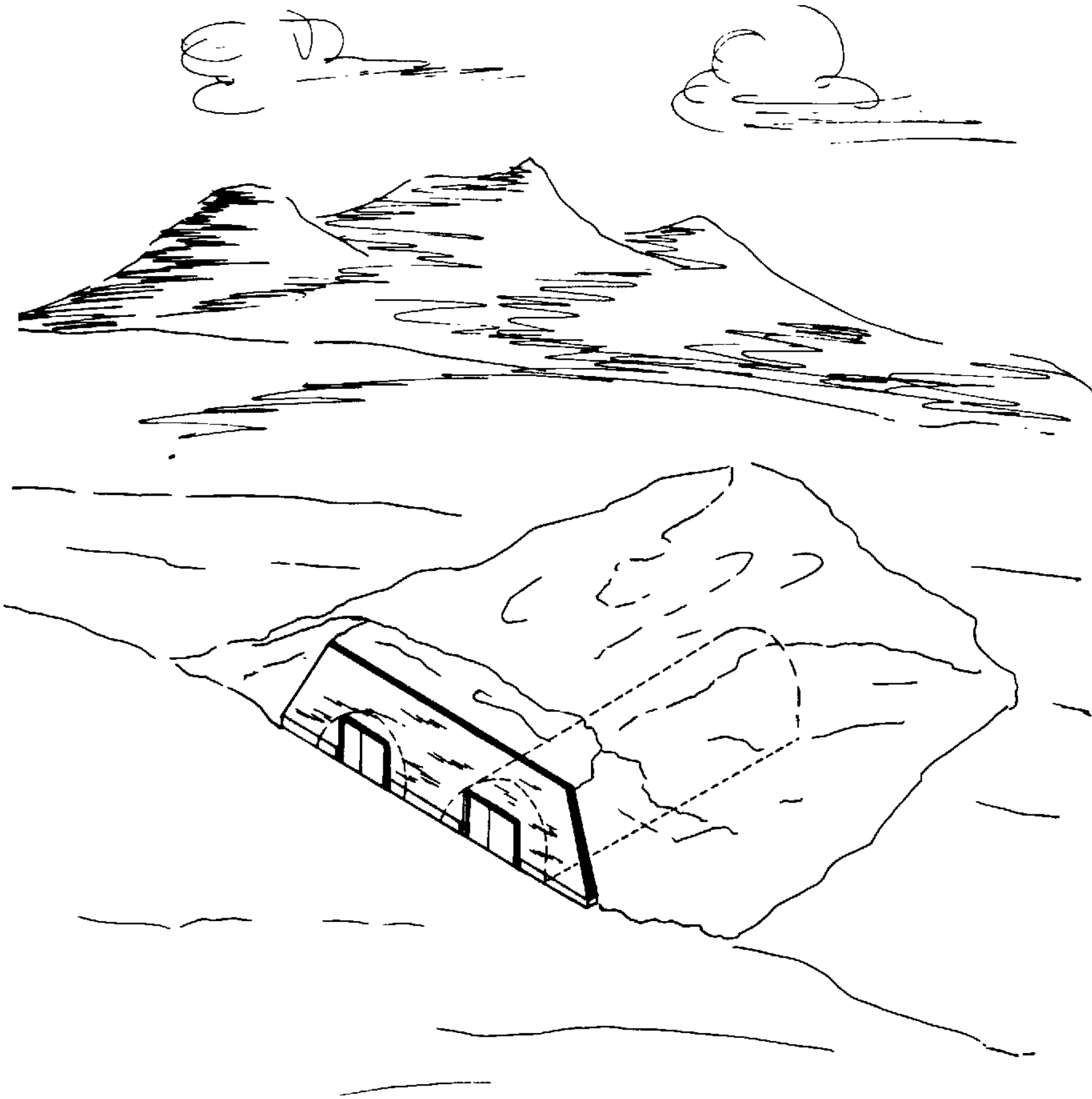


Figure 2.8 Igloo detail for CLEAN SLATE No. 3.

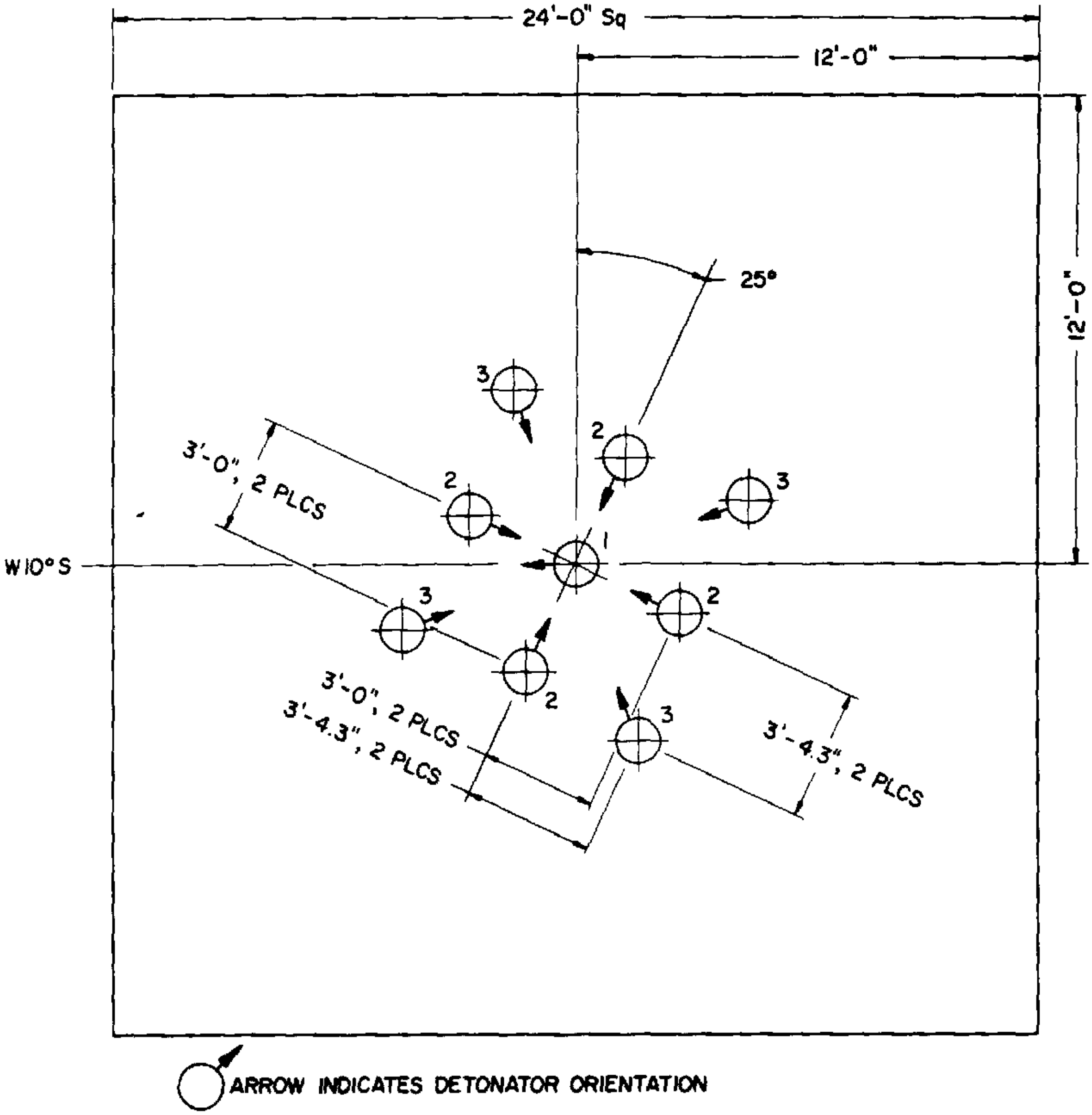


Figure 2.9 CLEAN SLATE No. 1 device array.

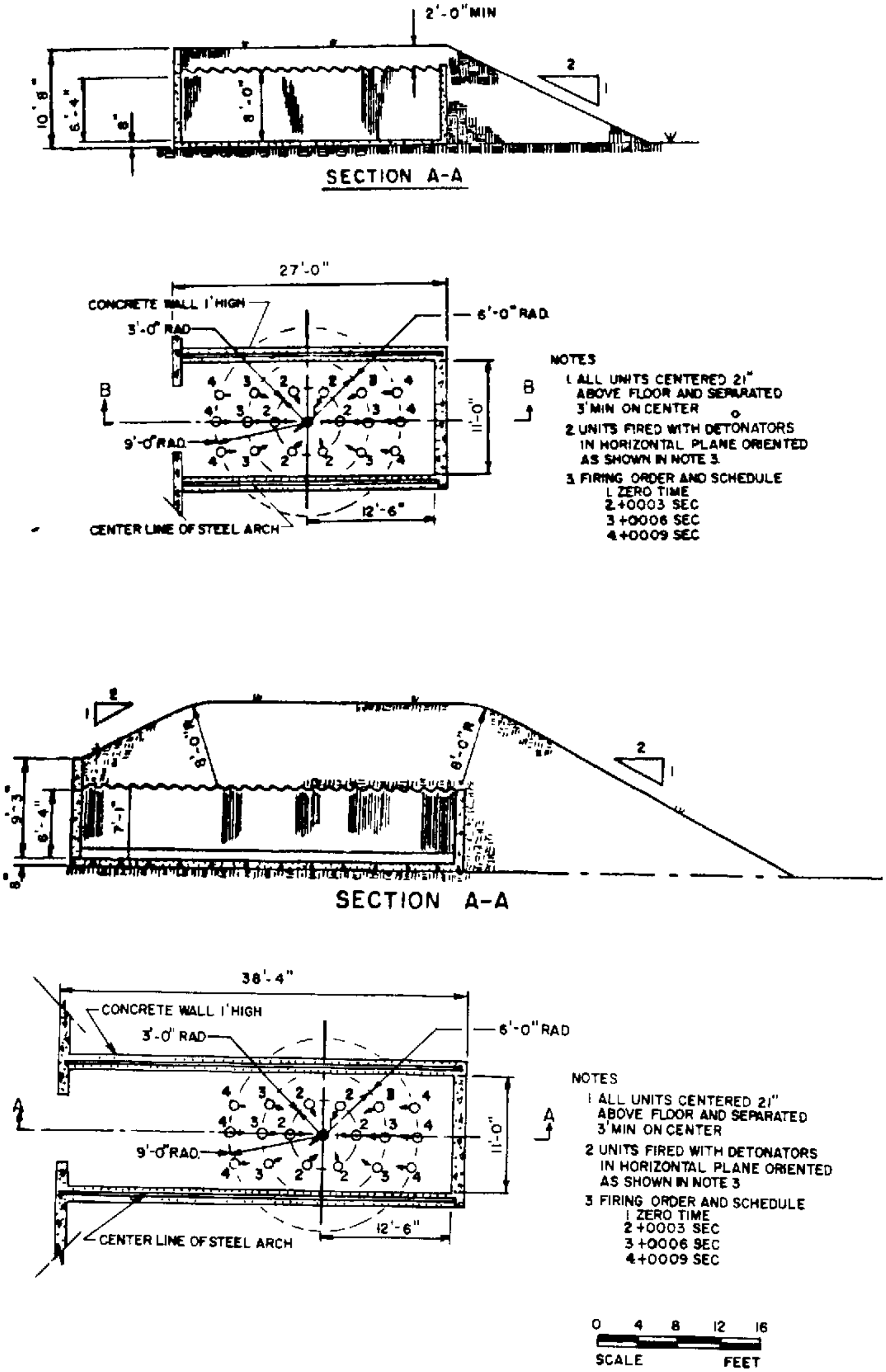


Figure 2.10 CLEAN SLATE research devices array.

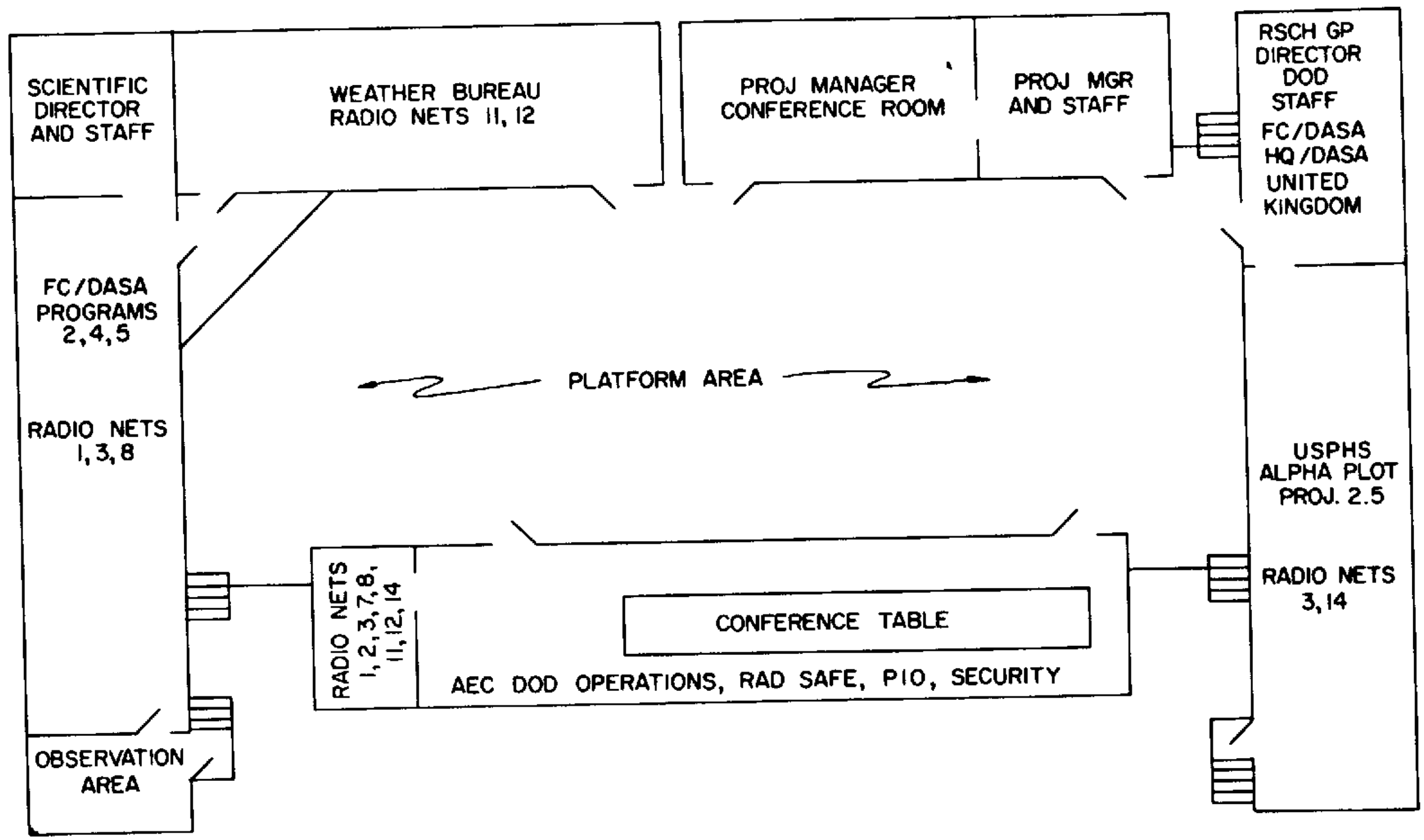


Figure 2.11 CP complex and trailer space assignments.

CHAPTER 3

PROJECT STRUCTURE AND EXECUTION OF EXPERIMENTS

3.1 INTRODUCTION

Operation Roller Coaster was a joint Atomic Energy Commission, Department of Defense, and United Kingdom (AEC/DOD/UK) research program conducted in a manner to insure that the three agencies were fully satisfied with the method of execution of the effort. (Overall responsibility was invested in the Research Group Director, the Scientific Director, and Deputy Scientific Director, representing the DOD, the AEC, and the United Kingdom, respectively, who formulated the details of the scientific program including the technical worth of instrumentation, its calibration, field position and orientation, sample recovery and packaging, data recording, etc.) The field execution of all experiments was done by project assignment to selected contractors. The organizational structure was shown before in Figure 1.1.

3.2 PROJECTS

Summary listing of projects by formal title, contractor, and brief statement of objectives is given below. Each project prepared a formal interim report, which appears as an appendix to this main text in Volume 2.

3.2.1 Project 2.1, Special Soil Deposition Measurements, Eberline Instrument Corporation. The primary objectives were: (1) to evaluate in detail the distribution and retention of plutonium and uranium in materials (e.g., concrete, steel, device fragments) at and immediately around GZ; and (2) to correlate, by chemical analysis, radiac meter readings of plutonium contamination with absolute surface levels of plutonium deposition (see Appendix B).

3.2.2 Project 2.2, Air Sampling Measurements, Nuclear Defense Laboratory. The objectives were: (1) to determine the size and activity of plutonium-bearing particles and their spatial distribution in the cloud (balloon-borne instruments) and near the surface; and (2) to determine the variability of these measurements with time (see Appendix C).

3.2.3 Project 2.3, Fallout Sample Collections, Isotopes, Inc. The objectives were: (1) to determine surface concentrations of plutonium and uranium as a function of position relative to ground zero; (2) to measure the time of arrival of contaminants and their accumulation rate with time and position from ground zero; and (3) to provide samples of fallout material in a form suitable for special particle characteristics study (see Appendix D).

3.2.4 Project 2.4, Micrometeorological Measurements, U. S. Weather Bureau. The objectives were: (1) to make a local climatological survey of the areas involved so that the specified conditions for the shot could be recognized in advance from the synoptic situation; (2) to provide observations and forecasts for preevent technical operations and for the implementation of the operational safety program; and (3) to make the following measurements during the period of interest of each event, for use in developing a cloud model: (a) surface wind velocity at positions throughout the sampling array, (b) wind velocity-height profiles, (c) temperature-height profile, and (d) turbulence-height profile (see Appendix E).

3.2.5 Project 2.5, Alpha Survey, Eberline Instrument Corporation. The objectives were: (1) to provide a large-area radiac survey of the plutonium-contaminated area and establish contamination level contours; (2) to provide data concerning approximate distribution and concentration of plutonium on the ground in support of other projects; (3) to provide a higher sampling density than was practicable by radiochemistry alone; and (4) finally, to attempt correlation of results by radiac meter readings with the more absolute results from chemical analysis of deposition samples (Appendices B and C).

Secondary objectives of the project were to investigate the feasibility of portable and mobile low-energy gamma detection techniques for uranium and plutonium and to rapidly delineate by these means surface-contamination boundaries to assist this and other projects in strategic equipment placement and recovery (see Appendix F).

3.2.6 Project 2.6a, Special Particulate Characteristics, U. S. Naval Radiological Defense Laboratory. The objectives were: (1) to determine the physical and chemical nature of the fallout resulting from non-nuclear detonations of weapons containing plutonium. The primary measurements were to include: (a) the total mass of fallout and the amount of plutonium and uranium collected per unit area, (b) the distribution of the fallout mass among various density fractions, (c) the fallout particle size distribution of each density fraction, and (d) the distribution of plutonium and uranium by particle size and particle density. In addition, limited studies will be made of the amount of soil present as well as the chemical state of the plutonium and uranium and their leaching and exchange behavior in several liquids (see Appendix G).

3.2.7 Projects 2.6b and 2.6c, Special Particulate Studies, Isotopes, Inc., and Tracerlab, Inc. The objectives included attempts to determine: (1) distribution of particles in terms of their active constituents; (2) distribution of active particles in terms of their microscopically observed sizes, giving mass and number distributions; (3) shapes of individual particles and variations in shape in groups of particles; (4) visible characteristics and comment generally on color, nature of surface, etc.; (5) composition of individual particles with particular emphasis on sizes a few microns and less; (6) approximate specific activity of individual particles and their variation with particle size; (7) presence or nonpresence of significant agglomeration effects; (8) general frangibility by noting breakup of particles on impactor slides; (9) indication of any deterioration in cascade sampler performance due to overloading or poor operating conditions; (10) particle size distributions including nonactive particles on the first stage of impactors on all CLEAN SLATE collections; (11) a simple and bulk disaggregation or particle disintegration with time in air and water; (12) by chemical analysis, following particle analysis, mass of active constituents; and (13) mass per unit area on deposition samples.

3.2.8 Project 2.7, Balloon Support, Sandia Corporation. The objective was to provide support for vertical air sampler curtains and cable-mounted meteorological equipment on all Roller Coaster events (see Appendix H).

3.2.9 Project 2.8, Off-Site Survey, U. S. Public Health Service. The objectives were: to detect and document any dispersal of contaminants beyond the operations area (see Appendix I).

3.2.10 Project 4.1, Biomedical Studies, University of Rochester. The objectives were: (1) to maximally expose several species of animals to the plutonium-rich aerosol produced by non-nuclear detonation of a plutonium-bearing device; (2) to sample and have analyzed each tissue (bone included) that might contain plutonium as a result of inhalation; and (3) to study plutonium deposition, retention, and metabolism, and correlate these with physical exposure environment by species (see Appendix J).

3.2.11 Project 5.1, Sample Handling and Processing Facility, Tracerlab. The objectives were to provide: (1) sample retrieval (from instruments), handling, and packaging; (2) on-site counting of selected samples; (3) decontamination of instrumentation for subsequent experiments; and (4) sample recordation, storing, and shipping for further analytical work (see Appendix K).

3.2.12 Project 5.2, Radiobiological Analysis, Hazelton Nuclear Science Corporation (5.2A), Tracerlab (5.2B), Eberline Instrument Corporation (5.2C), and Isotopes (5.2D). The objective is to provide accurate laboratory analysis of animal tissue, bone material, feces, urine and other animal associated samples for plutonium content. Uranium content analysis will be performed on five percent of all available samples. With the exception of the long term animal sacrifice program, it is expected that the radiobiological analysis on all present samples will be completed on or before 1 April 1964.

3.2.13 Project 5.3, Radiochemical and Physiochemical Analysis, Hazelton Nuclear Science Corporation (5.3A), Tracerlab (5.3B), Eberline Instrument Corporation (5.3C), Isotopes (5.3D). The objective is to provide large scale laboratory analysis of soil, air sample filters, and fallout samples for plutonium content. Uranium content analysis will be performed on five percent of all samples available. It is expected that radiochemical and physiochemical analysis will be completed on or before 1 April 1964.

CHAPTER 4

EVENT DOUBLE TRACKS

4.1 DESCRIPTION OF THE EVENT

4.1.1 Instrumentation and Animal Array. Instrumentation for DOUBLE TRACKS was in accordance with the experimental plan, with the exception of failure to achieve all the balloon arrays wanted.

The animal array was divided between Arcs E, G, and I and, each animal rack was instrumented with Casella MK II impactors and total air samplers. Full details of animal loading and positioning are given in Appendix J.

4.1.2 Balloon Arrays. Due to balloon losses in the period from mid-April onwards, it proved impracticable to mount the second balloon curtain. The main curtain on Arc B was instrumented as planned, apart from minor exceptions. The array of individual UK balloons planned to be located on Arc R was also necessarily modified and moved to Arc J to form the second curtain.

There were also losses of these individual balloons in the preshot phase. The number of the larger type balloons, capable of carrying the required two cascade impactors, was reduced to three. The remaining five were of a smaller variety and carried only sticky sampling cylinders at 50-foot height intervals to 1000 feet.

4.1.3 Preshot Events. DOUBLE TRACKS was originally scheduled for 1 May 1963 but due to balloon failures, it was delayed until 0100, 13 May. On 12 May, the array was instrumented, and by 2300 the balloon arrays had been rigged and raised. The expected northerly drainage flow was not established. Fairly strong, southerly upper winds prevailed to keep the resultant too far in the east. The shot was cancelled at 0300 and the balloon arrays were derigged.

On the forecast of a thermal trough over the area on 14 May, H-hour was rescheduled for 0100, 15 May. During 13 May, high winds up to 40 knots occurred, and on 14 May checks were made for deterioration of instrumentation, fallout collectors, etc. which had remained in the field; faults found were rectified. Two of the original three balloon curtains were again instrumented and in position by 2359.

4.1.4 Shot Phase. With the exception of wind speed, acceptable meteorological conditions were established by 0100, and the movable array was adjusted to line up with the wind direction. A temperature inversion of about 2.5°C at 500 feet had developed but wind speeds at GZ were too high, in the range 13 to 15 knots. Further down the array, however, they were in the acceptable range (below 10 knots) (see Appendix E).

At 0230, a decrease in wind speed was apparent. This trend continued, and DOUBLE TRACKS was fired at 0255, 15 May 1963. Wind speed at GZ was 11 knots and of decreasing intensity further down the array. Wind shear of some 25 degrees existed within the vertical extent of the cloud.

4.1.5 Postshot Phase. With the exception of the incremental fallout samplers and a few other minor failures, all instrumentation operated correctly.

Cloud photography using a sequence of 50-million candlepower flash bulbs was successful. Details of photographic equipment and its positioning are given in Appendix L.

Delineation of the fallout area was accomplished first by use of Project 2.5 mobile gamma scanner. This information was used to start the alpha-survey teams in optimal locations. This survey was completed before noon of D-day (see Appendix F).

Sample collection took place under good weather conditions. All samples were carried to Project 5.1, On-Site Laboratory, for identification, counting, and packaging.

4.2 RESULTS

At the time of preparation of this report, the only results available comprised:

(a) Alpha survey data

(b) Field alpha counting of:

(1) A proportion of air samplers

(2) A proportion of planchets from fallout collector stations

(3) The majority of sticky cylinders from the balloon arrays

(c) High speed film of the detonation and stills from cloud photographs. These still require detailed analysis but Figure 4.1 shows two views of the cloud about the time of intercept of the first balloon curtain. A three-frame extract from the high speed movie appears as Figure 4.2 to show jet extent and early fireball development.

4.2.1 Alpha Survey. Alpha survey results have been plotted to show rough fallout contours on Figures 4.3 and 4.4. The PAC-3G survey meter is set by gain adjustment to read 420 cpm on a standard source equivalent to 1 $\mu gm/m^2$ and the conversion of survey data to contour plots has been based on this relationship. Due to the effects of self-absorption, this method underestimates the concentration by a factor which is dependent on both down-wind and cross-wind positions in the fallout area.

Certain microscope slides from Arc H were studied in the field by R. F. Carter of UKAEA, using an autoradiographic technique he developed. Description of this study and detailed results are given in Appendix M. Especially informative is the comparison of autoradiographic results with levels deduced from alpha survey and counting of fallout planchets. On the arc checked, H, the activity seen by autoradiography was almost always higher by a factor between 1 and 5 with an average of 2 to 3.

It will be noted that the factor referred to above varies considerably across the arc; an average value lies between 2 and 3.

4.2.2 Air Concentrations. From the counting data on air sampler stages, an assessment has been made of the total airborne concentration contours, Figure 4.5, and of that part of the airborne concentration likely to be a respirable hazard (Figure 4.6). The latter is a broad approximation and is deduced by subtracting from the total impactor sample the material on Stages 1 and 2 of both Andersen and Casella impactors.

4.2.3 Cloud Concentration and Dimensions. The cloud photographs already presented as Figure 4.1 should be viewed as a correlary of the data from field counting of sticky cylinders; these data are shown as Figure 4.7. The farther balloon curtain (Arc J at 13,000 feet) also contained sticky cylinders whose measured activities led to Figure 4.8.

4.3 DISCUSSION

Field counting is qualitatively satisfying, even useful to get semi-quantitative information. Unfortunately, until the precise results are available, the real quality of data now in hand cannot be judged. Therefore, caution must be exercised in approaching any conclusions as yet.

The degree of experimental success was clearly high and good analytical steps to come will produce a tremendous supply of data heretofore unavailable.

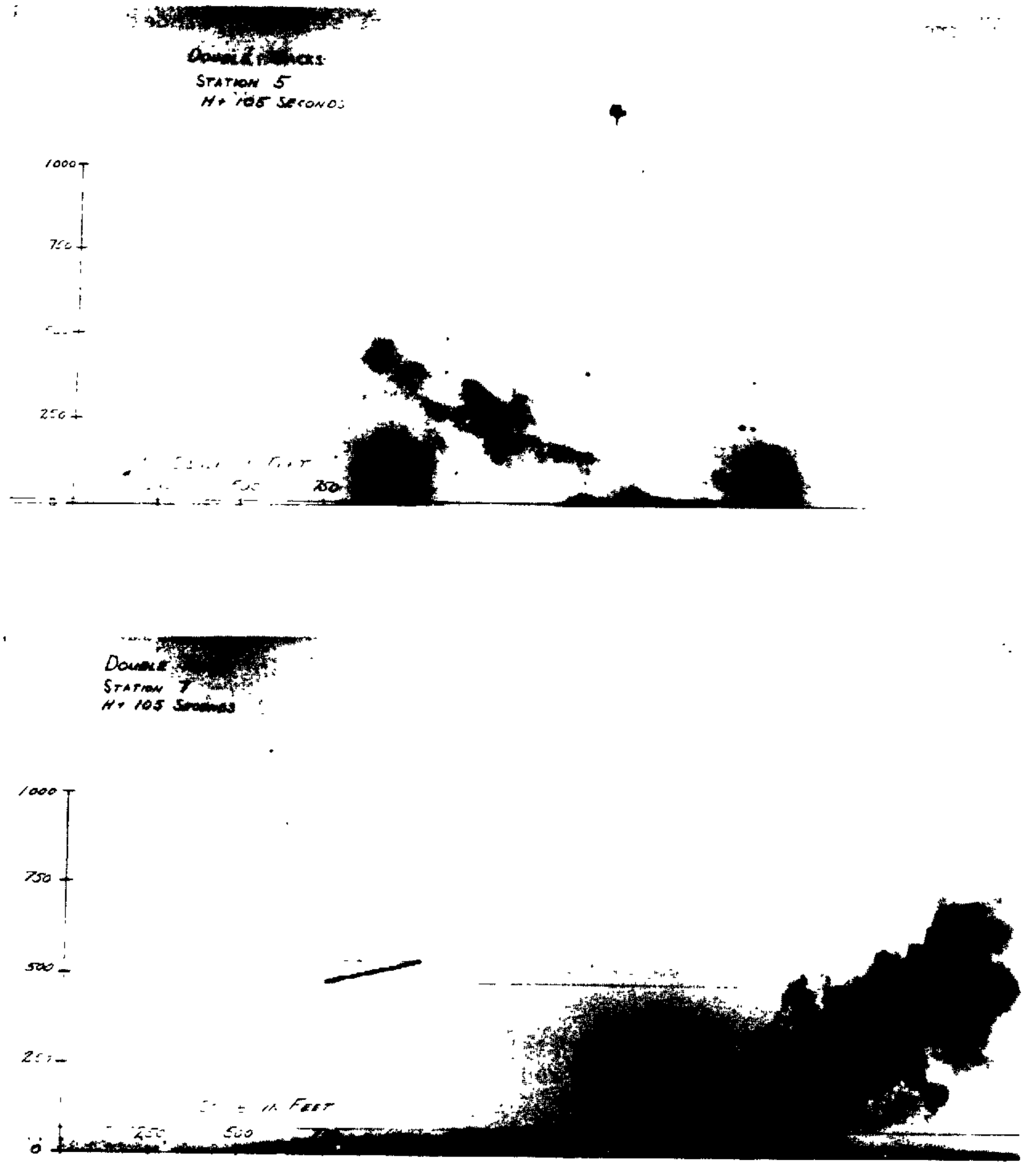
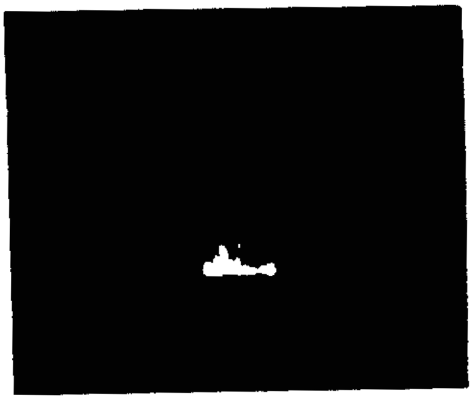
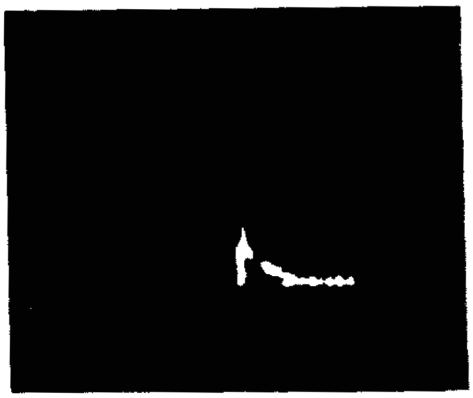


Figure 4.1 Two views of DOUBLE TRACKS cloud at time of first balloon intercept. (Sandia Corporation photos)



H + 4 milliseconds



H + 14 milliseconds

H + 33 milliseconds

Figure 4.2 High-speed DOUBLE TRACKS sequence from 1,500 feet north of ground zero. (Sandia Corporation photos)

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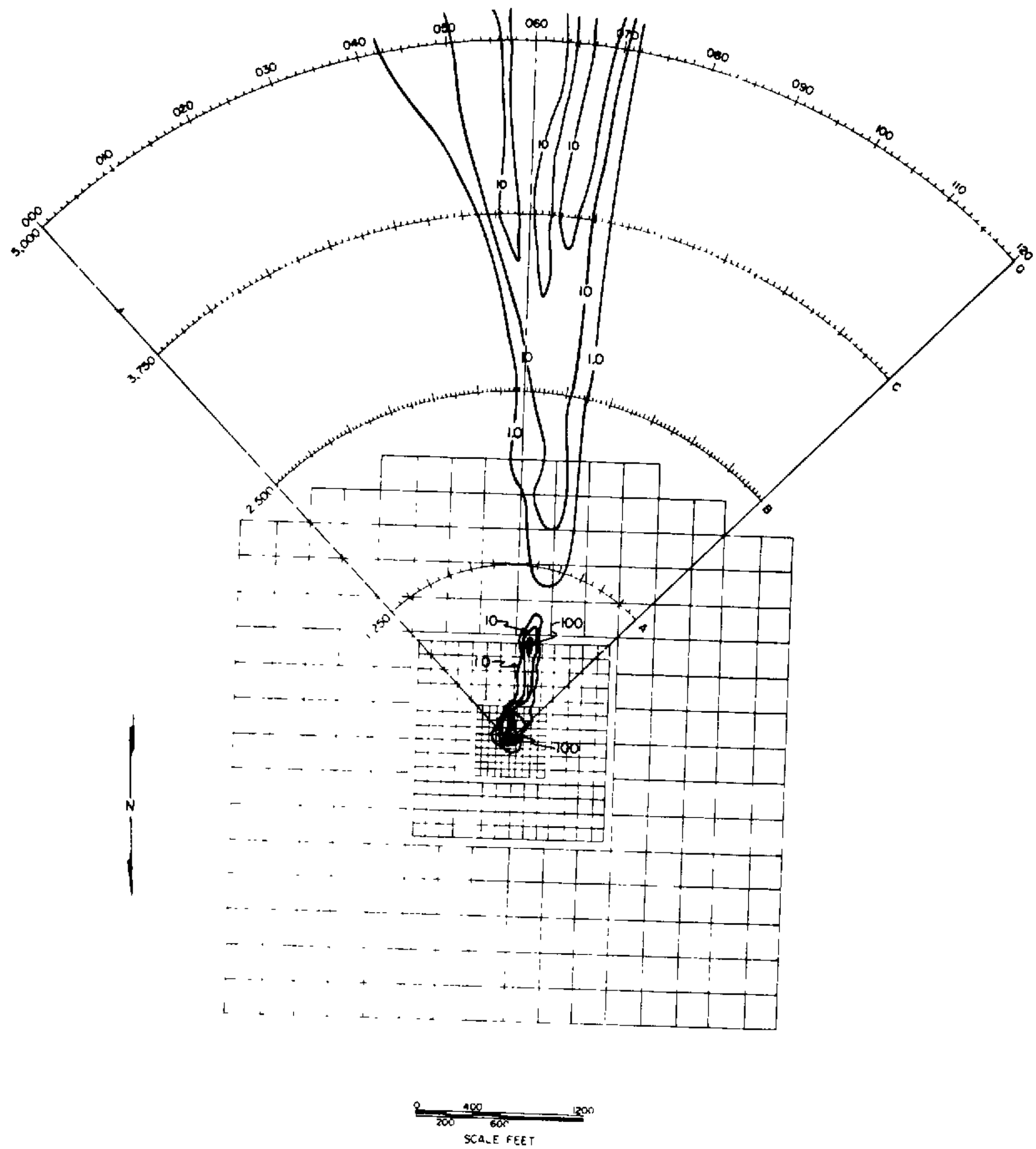


Figure 4 3 DOUBLE TRACKS deposition contours by alpha survey in $\mu g/m^2$.

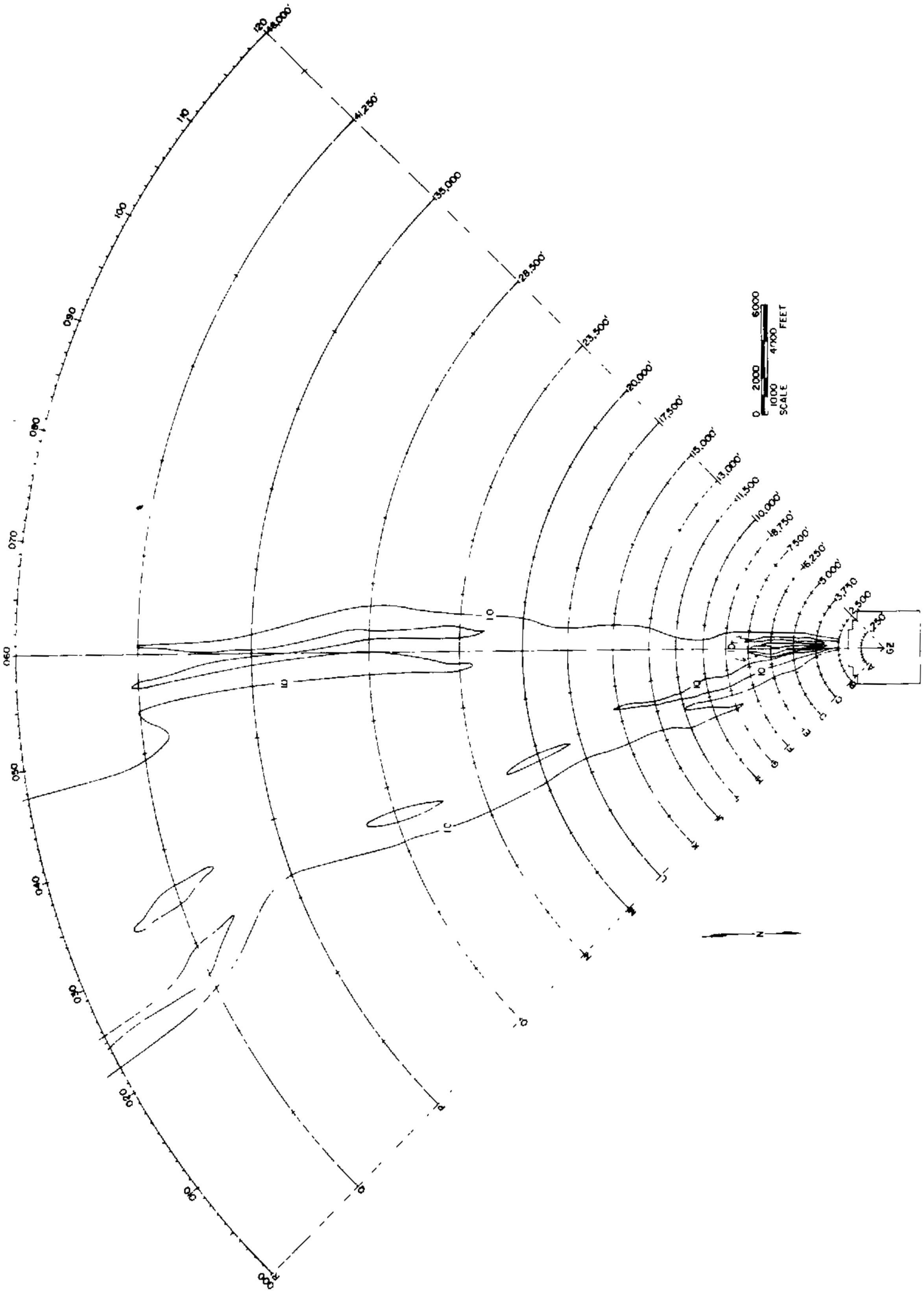


Figure 4.4 Deposition contours by alpha survey in $\mu g/m^2$, DOUBLE TRACKS.

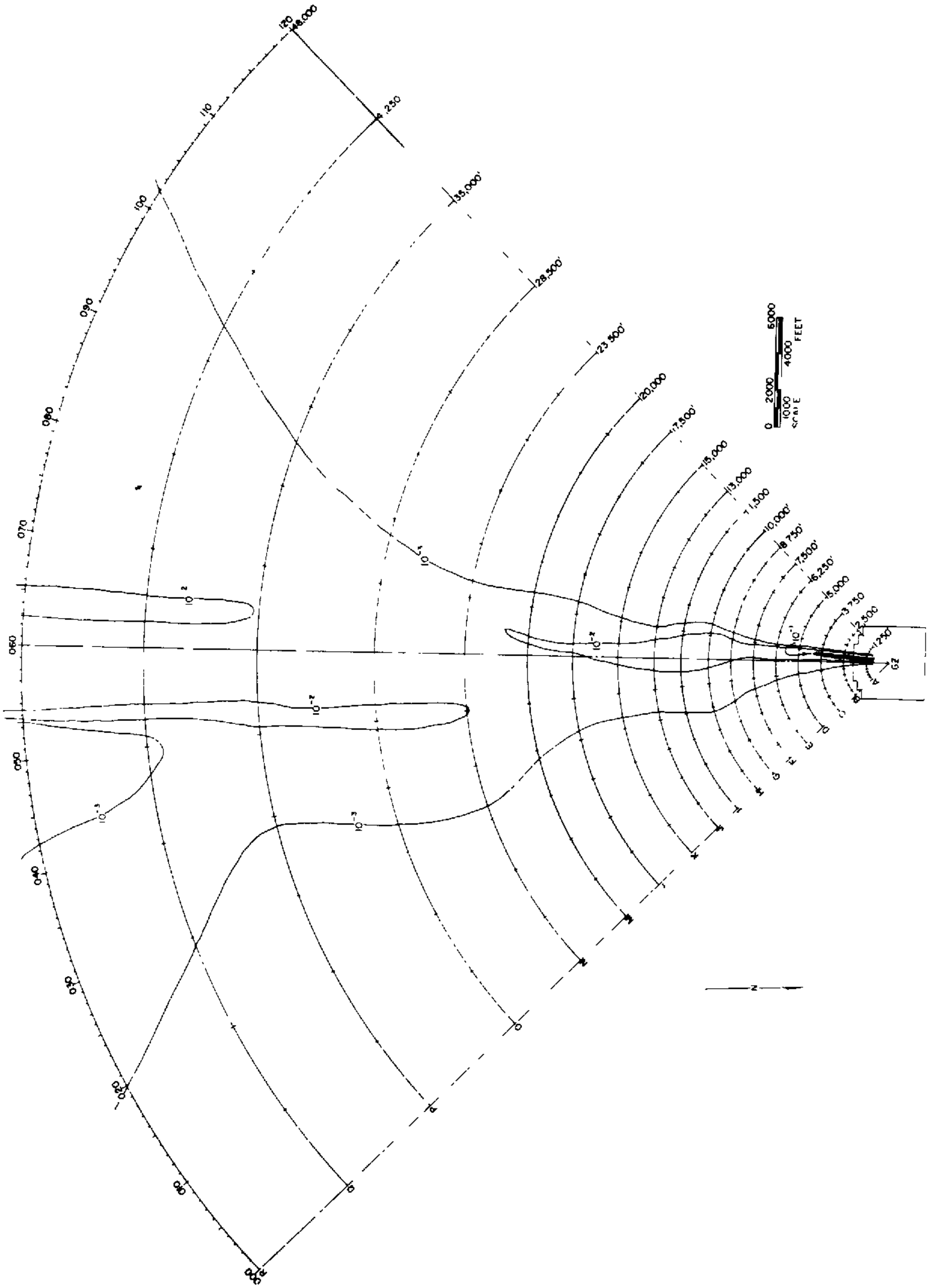


Figure 4.5 Total plutonium (in air sampler) during DOUBLE TRACKS cloud passage.

Figure 4.5 Total plutonium (in air sampler) during DOUBLE TRACKS cloud passage. cloud passage.

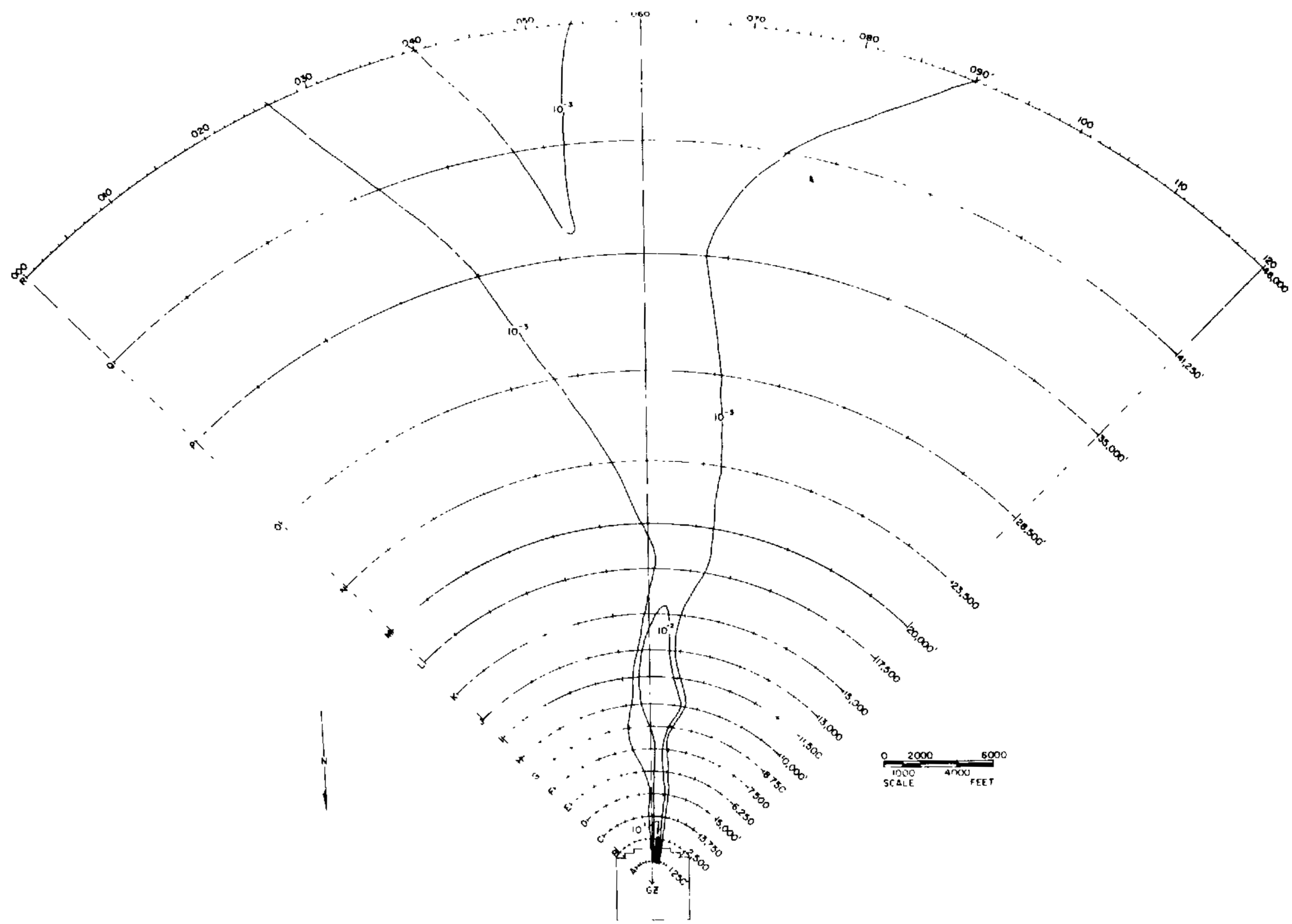


Figure 4.6 Respirable plutonium (in air sampler) during DOUBLE TRACKS cloud passage. DOUBLE TRACKS cloud passage.

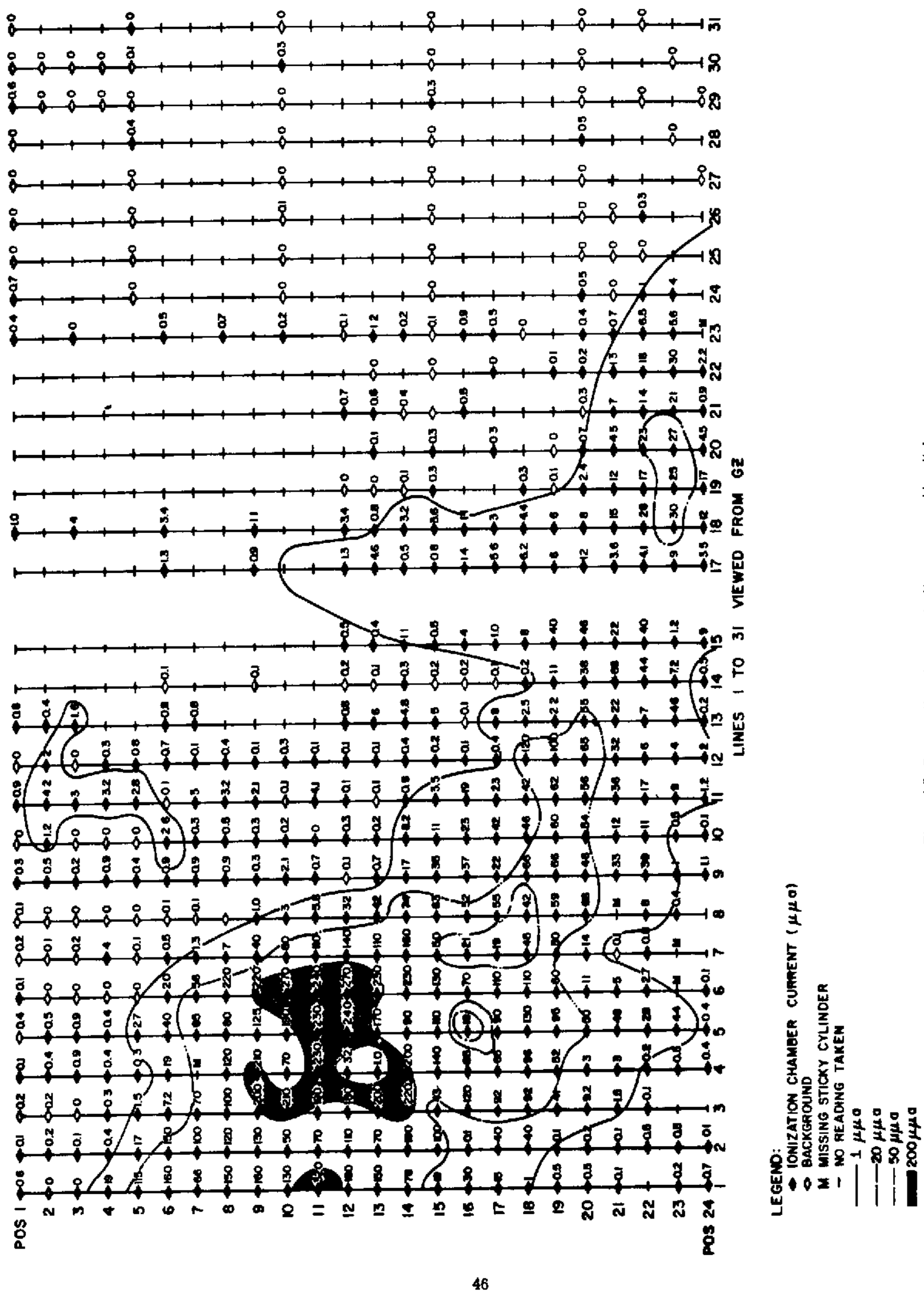


Figure 4.7 Comparative air concentrations measured by sticky cylinder collections on DOUBLE TRACKS at 2,500 feet.

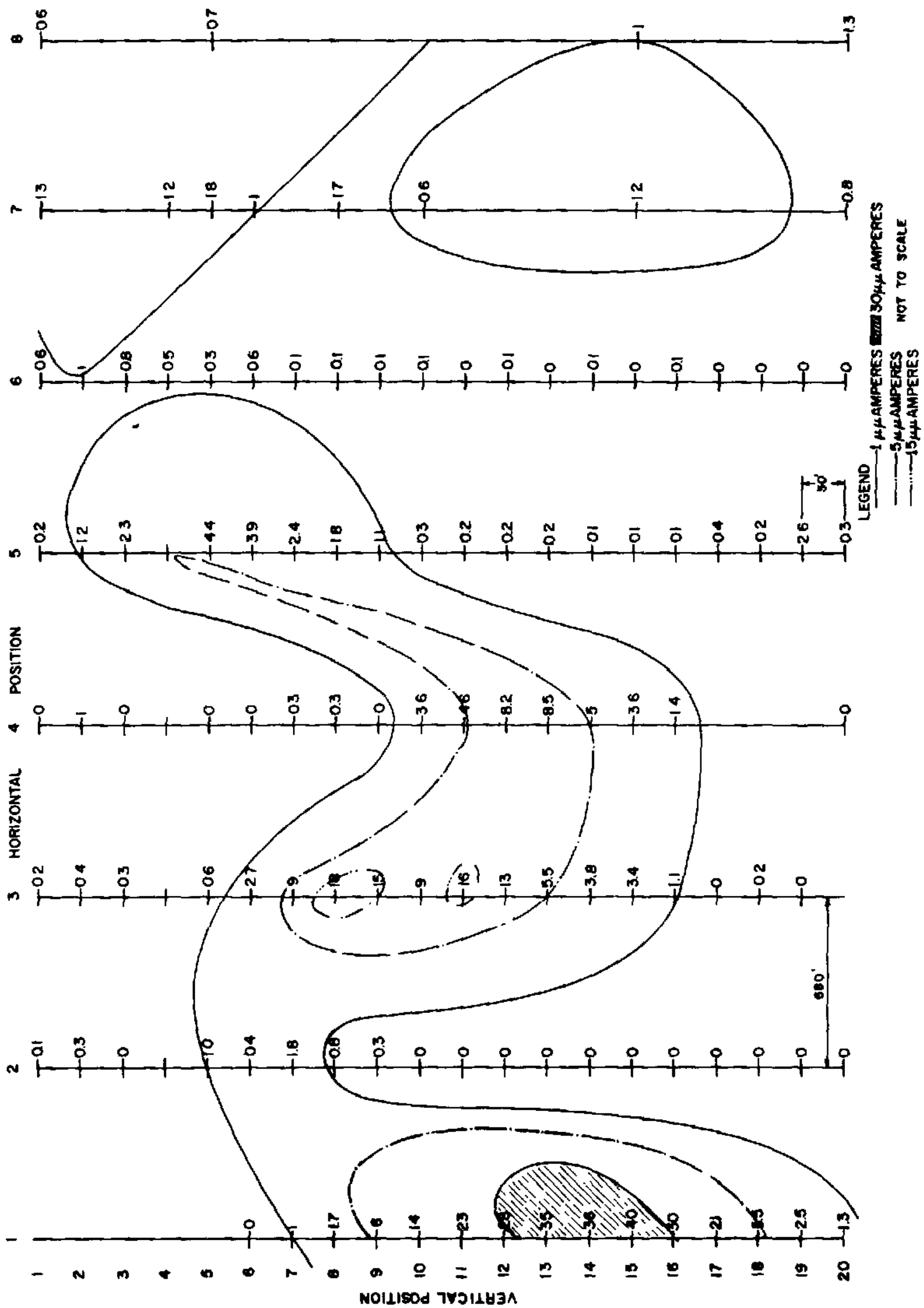


Figure 4.8 Comparative air concentration by measurement of sticky cylinder collections on DOUBLE TRACKS at 13,000 feet.

CHAPTER 5

EVENT CLEAN SLATE NO. 1

5.1 DESCRIPTION OF THE EVENT

5.1.1 Instrumentation. Instrumentation on the array was as planned, with the following exceptions:

(a) At 21 stations throughout the array, water-filled trays were exposed to collect samples suitable for solubility studies.

(b) Since additional air sampling equipment was available, some forty additional instruments were positioned throughout the array at existing sampling stations (see Appendix C). This will eventually allow some estimate to be made of the relative sampling of different instruments at the same location.

(c) Several stations were equipped with double fallout collectors to allow a similar comparison to be made on the variation of fallout on separate collecting surfaces at the same location.

5.1.2 Balloon Arrays. Continuing high winds between events caused further damage to Project 2.7 balloons and it again proved impracticable to rig a second balloon array. This event was therefore planned with the balloon curtain on Arc B only. It was not possible to utilize the individual UK balloons, since their lift capacity flying at the required minimum of about 3,000 feet was inadequate.

5.1.3 Preshot Events. It was anticipated that the minimum length of time between events to allow efficient sample collection, equipment decontamination, and redeployment would be seven days. CLEAN SLATE No. 1 was therefore scheduled for 22 May. On 20 May, the main balloon was damaged during inflation and had to be deflated for repair. A 24-hour delay was therefore called.

On 22 May, the array was instrumented and the balloon curtain rigged.

Suitable meteorological conditions failed to occur, and H-hour was changed to 0100, 24 May. During 23 May, damage to a catenary cable of the balloon array caused a further delay, and H-hour was rescheduled for 0100, 25 May. Instrumentation on the array was inspected periodically to ensure that it remained in a satisfactory condition.

5.1.4 Shot Phase. On the night of 24/25 May, with northerly synoptic winds supplementing the drainage flow, wind speeds were initially too high. At approximately 0345, the winds commenced to decrease in speed and in the first 2000 feet there was an almost complete absence of directional shear. CLEAN SLATE No. 1 was fired at 0417, 25 May,with a wind speed of 12 knots, a temperature inversion of approximately 5°C 600 feet deep, and with very small directional wind shear (Appendix E).

5.1.5 Postshot Phase. Delineation of the fallout area was carried out as described for the DOUBLE TRACKS event. Sample recovery was accomplished satisfactorily.

The remote switching system for the eastern half of Arc F failed to operate,with the consequent loss of air samples on this half-arc. The incremental fallout samplers were partly successful; three stations operated fully.

5.2 RESULTS

The results available for this event are on the same basis as for DOUBLE TRACKS.

5.2.1 Alpha Survey Results. These are presented in Figures 5.1 through 5.4. As yet no autoradiographic investigation been carried out on CLEAN SLATE No. 1 samples, and it must be assumed at this stage that the contours given by alpha survey are an underestimate of deposited material by a factor of between 2 and 3 in general.

5.2.2 Air Concentrations. A contour of total airborne concentration was not prepared,but the sampler data are given in Appendix C. No attempt was made to single out the respirable airborne concentration due to the very low total levels.

5.2.3 Cloud Concentrations and Dimensions. Typical cloud photographs at the time of passage through the balloon curtain are shown as Figure 5.5 with suitable dimension scales. High speed sequence is again given (Figure 5.6). Counting results from balloon-borne sampling equipment are shown in Figure 5.7.

5.3 DISCUSSION

Wind speeds were higher than optimum but within the limits adopted for the experiment. Thus, the accountable percentage of total plutonium released will be lower than expected. The intercept pattern on the balloon curtain is reassuring, however, and quite a good source description will probably result.

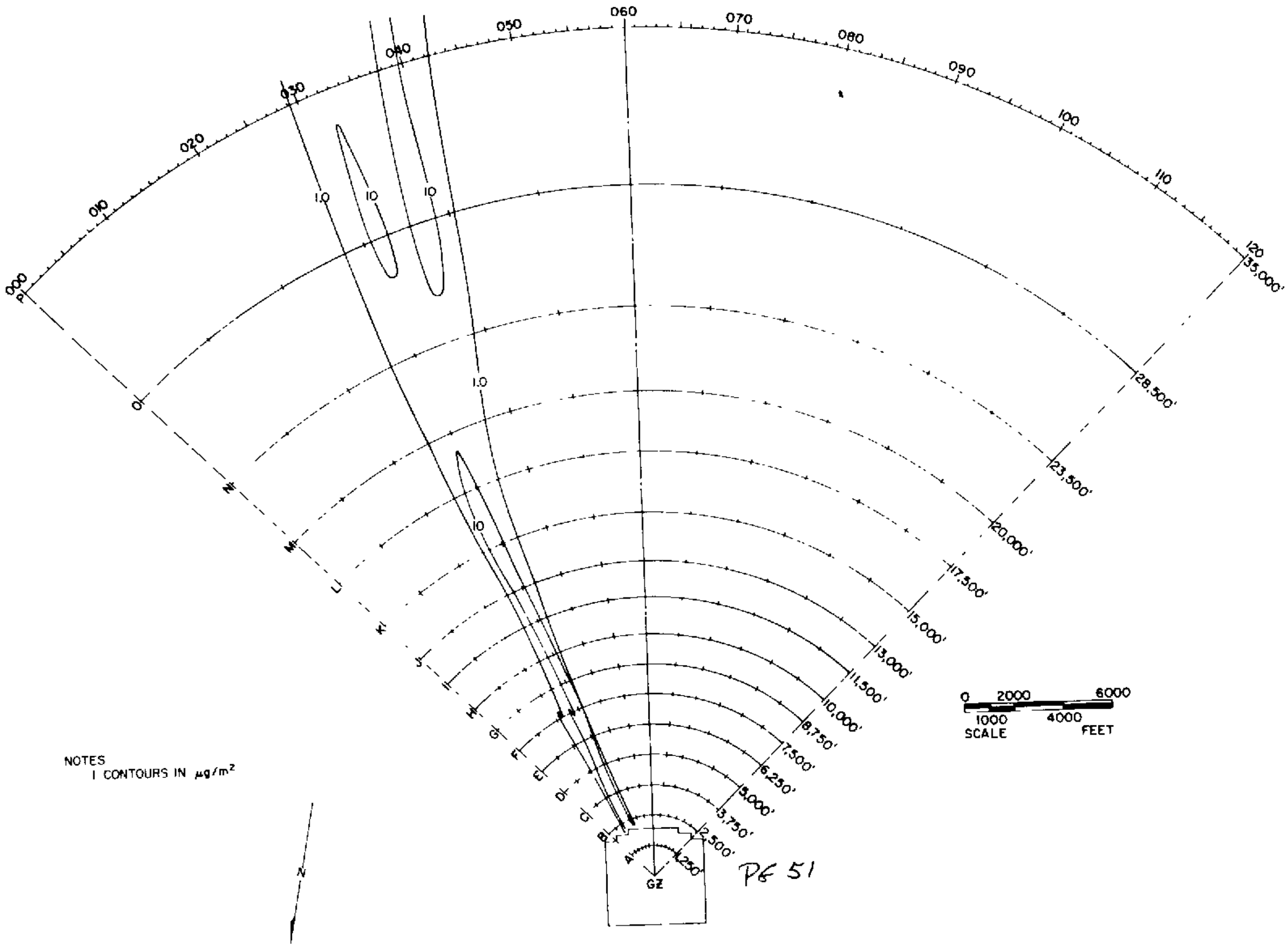


Figure 5.1 CLEAN SLATE No. 1 deposition contours by alpha survey in $\mu g/m^2$.
survey in $\mu g/m^2$.

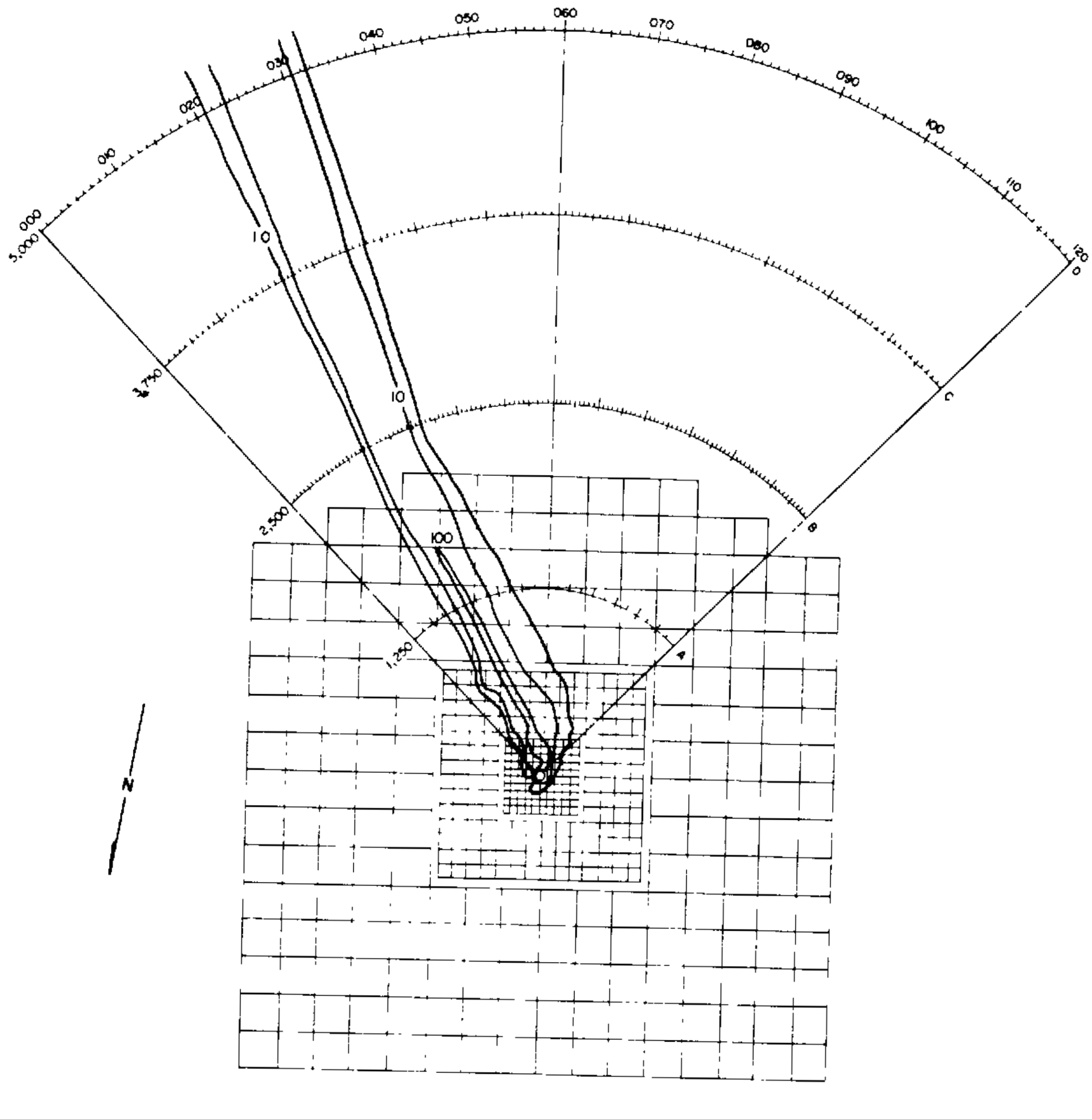


Figure 5.2 Deposition contours by alpha survey in μg/m², CLEAN SLATE No. 1

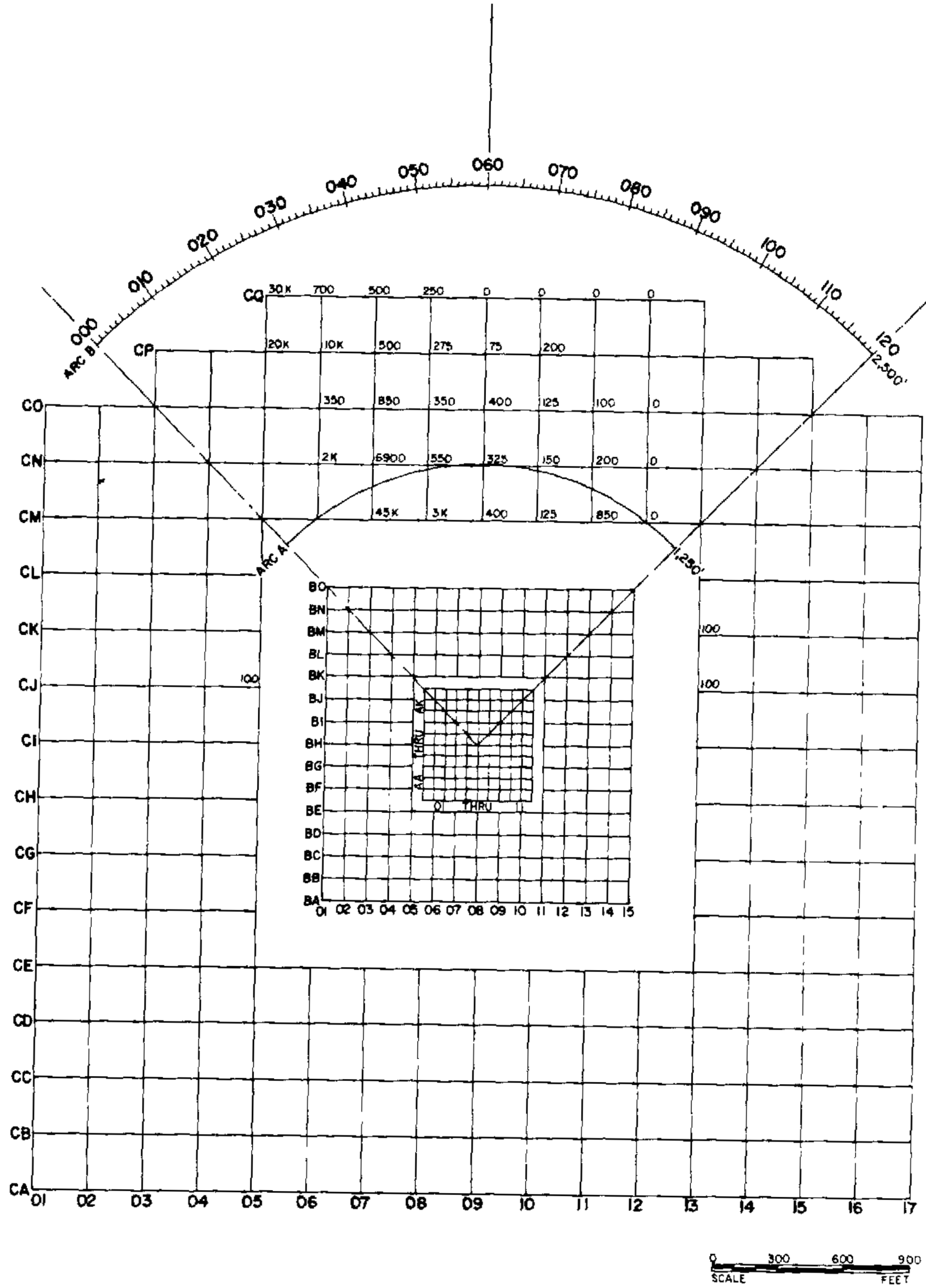


Figure 5.3 CLEAN SLATE No. 1 alpha survey meter readings (cpm) in GZ area.

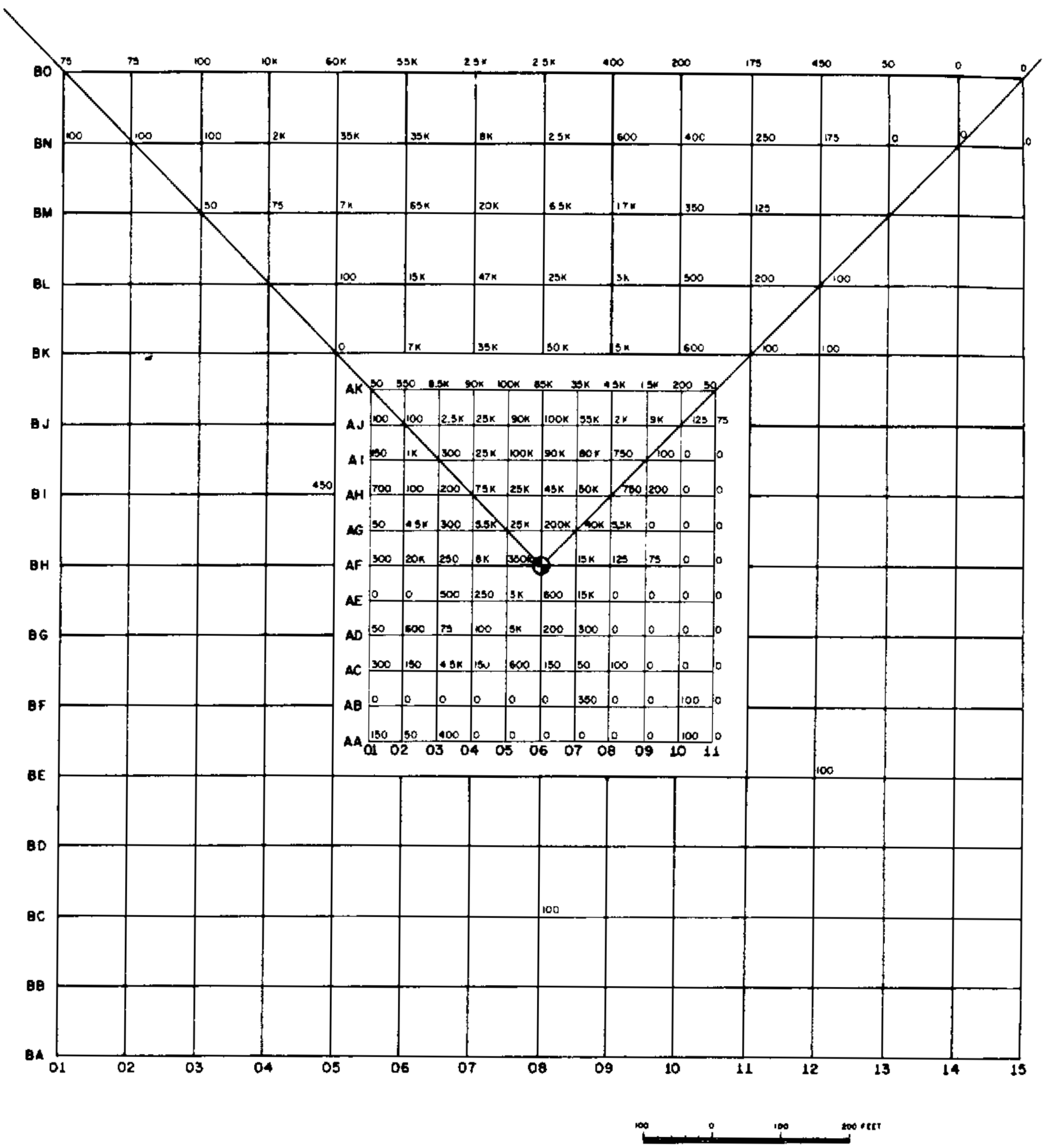


Figure 5.4 CLEAN SLATE No. 1 alpha survey meter readings (cpm) in GZ Areas A and B.

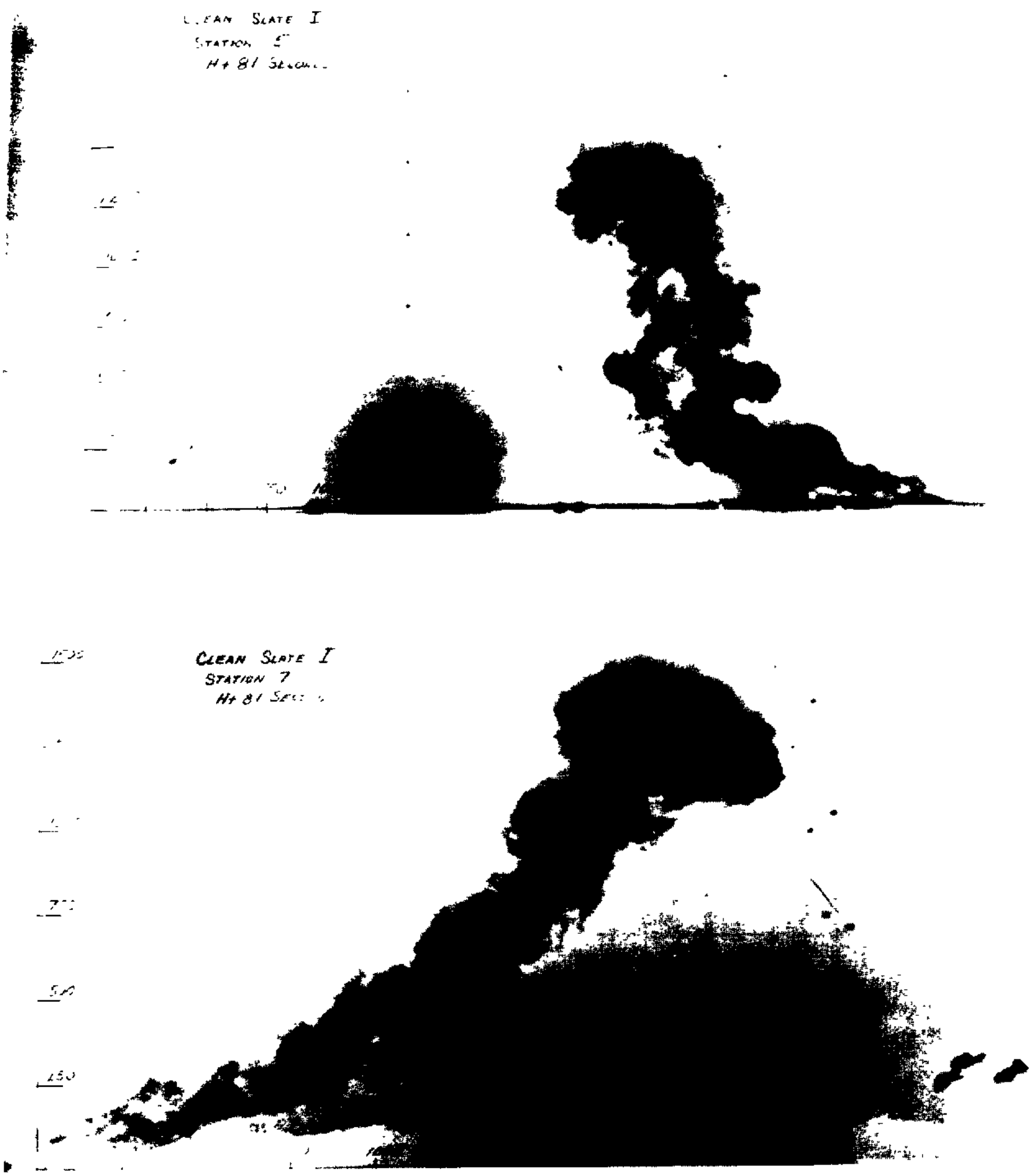
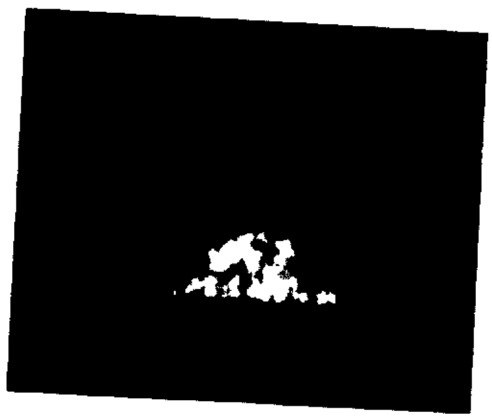


Figure 5.5 Two views of CLEAN SLATE No. 1 cloud at time of balloon curtain intercept.

H + 4 milliseconds



H + 14 milliseconds

H + 33 milliseconds

Figure 5.6 High-speed CLEAN SLATE No. 1 sequence for 1,500 feet north of ground zero. (Sandia Corporation photos)

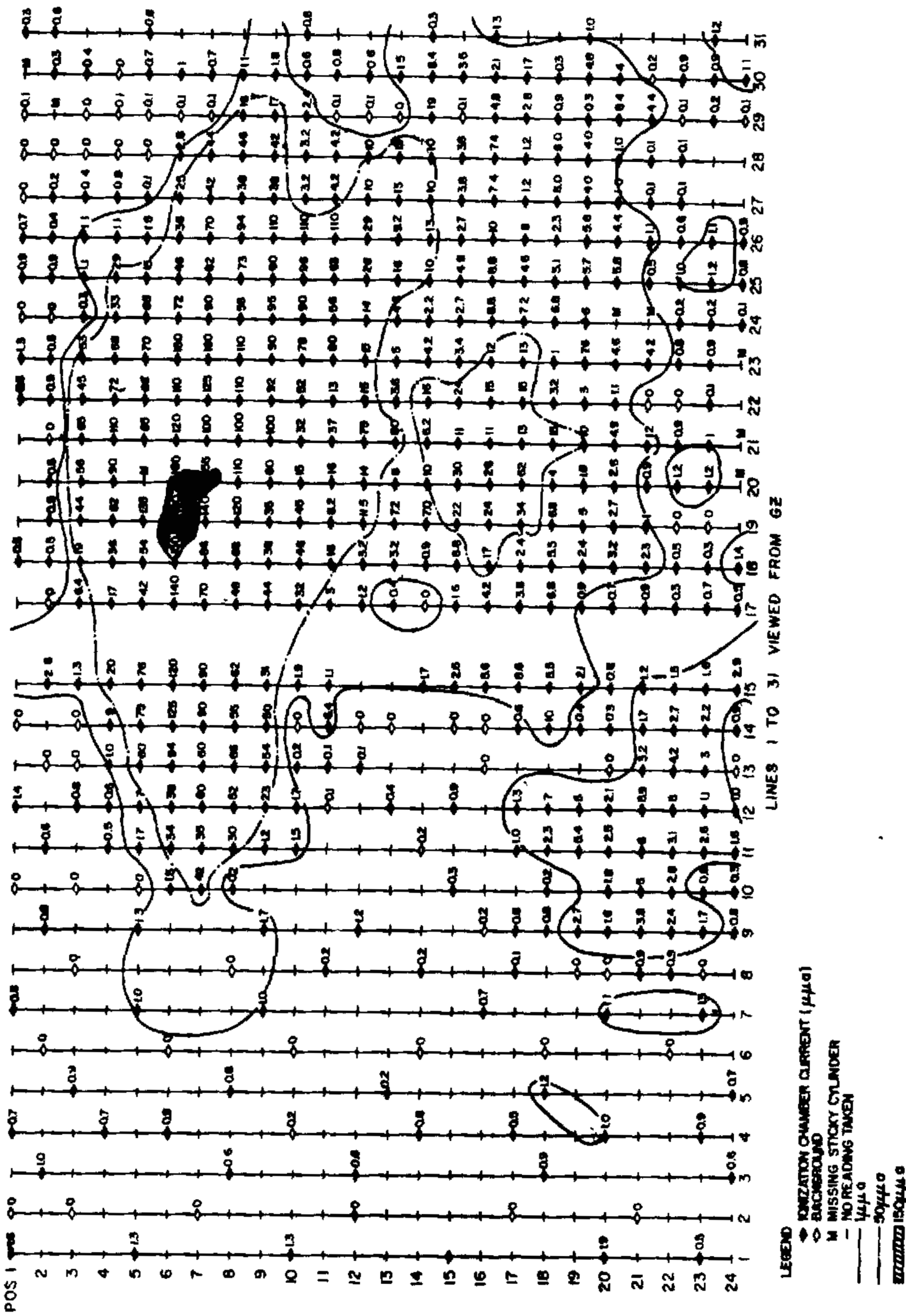


Figure 5.7 Comparative air concentration measured by sticky cylinder collection on CLEAN SLATE No 1

CHAPTER 6

EVENT CLEAN SLATE NO. 2

6.1 DESCRIPTION OF THE EVENT

6.1.1 Instrumentation. Instrumentation employed in addition to that originally planned was as follows:

(a) At 35 stations in the movable array and at the two mobile stations, water-filled trays for the collection of solubility samples were set out (see Figures 6.1 and 6.3).

(b) Air sampling equipment not originally required because of the lesser area instrumented here was assigned either to duplicate positions for instrument comparisons or set to intensify coverage or extend it (see Figures 6.1, 6.2, and 6.3).

(c) Two Casella MK II impactors were placed on each of two towers (Figure 6.1) located close to the bunker door to obtain samples of material from the fireball shortly after it issued from the door. One set of impactors was mounted on a 30-foot tower, the other on a 60-foot tower. In each set, one impactor sampled for one second after zero time and the other for three seconds. The impactors were suitably shielded from the heat of the fireball. Details are given in Appendix C.

6.1.2 Balloon Arrays. The main balloon array was instrumented as planned and located on Arc B. In addition, three small UK balloons were located within 500 feet of GZ (Figure 6.4); two were placed to obtain early samples from the dirt cloud produced by the venting of the bunker roof, and one was placed to obtain an early sample of the fireball issuing from the bunker door.

6.1.3 Animal Array. No participation of Project 4.1 was planned for any of the CLEAN SLATE events. Certain animals were, however, available and two groups, ten burros and ten sheep, were positioned on Arc E. Further details are contained in Appendix J.

6.1.4 Preshot Events. CLEAN SLATE No. 2 was scheduled for 0100, 31 May. The array was instrumented on 30 May and the balloon curtain successfully rigged by 2300.

6.1.5 Shot Phase. CLEAN SLATE No. 2 was fired at 0347, 31 May 1963. Mean wind speed within the cloud height was approximately six knots, with some forty degrees of directional shear. A weak temperature inversion of 2°C to 500 feet was followed by a deep isothermal layer to over 1,500 feet. Due to a wind shift occurring at shot time, a large portion of the cloud passed to the east of the balloon curtain on Arc B, although the fallout was contained within the array.

6.1.6 Postshot Phase. Alpha survey on the main array was completed by 1100 hours on 31 May, but parts of the GZ grid were not completed before heavy rain intervened. All air samples were satisfactorily collected. At 1300 hours, unexpected heavy rain commenced and continued for several hours. Due to this, a considerable number of fallout samples, planchets, and microscope slides were rendered useless. Details of fallout samples recovered before this rain are given in Appendix D.

Both towers located in front of the bunker door collapsed due, it is presumed, to impact of heavy fragments from the bunker doors and front wall. The impactors were recovered and the stages counted. No assessment of the sampling time is possible, but the samples will be analyzed for quantity of plutonium and for particle size and nature.

In general, the incremental fallout samplers worked satisfactorily.

6.2 RESULTS

6.2.1 Alpha Survey Results. Alpha survey results are presented as Figures 6.5 and 6.6. No results are available for the A grid and part of the B grid on the GZ array, since these were not completed before heavy rain occurred.

6.2.2 Airborne Concentrations. Total airborne concentrations based on the field alpha counting of impactor stages is given as Figure 6.7. Respirable airborne concentrations were assessed as previously described; they are shown as Figure 6.8.

6.2.3 Cloud Centrations and Dimensions. Photographs of fireball issuance from the bunker are given in Figure 6.9. Shots of the cloud at the time of passing the balloon curtain appear as Figure 6.10. As mentioned, the cloud mainly by-passed the curtain to the east and only the air samplers on the easternmost vertical cables showed any activity. It will not be possible therefore to indicate concentrations over major portions of the cloud. Figure 6.11 does provide sticky cylinder count data for the intercepted fraction of the cloud.

6.3 DISCUSSION

The low wind speed led to higher than expected accountability of plutonium on the reduced area instrumented despite the unfortunate directional wind shift that caused missing the balloon curtain. Final data should permit excellent documentation of the shot from ground instruments and provide adequate comparison with CLEAN SLATE No. 1 and 3. In this shot-to-shot relating, cloud model computations will play a prime role (see Appendix N), since there is really no experimental substitute for balloon curtain data.

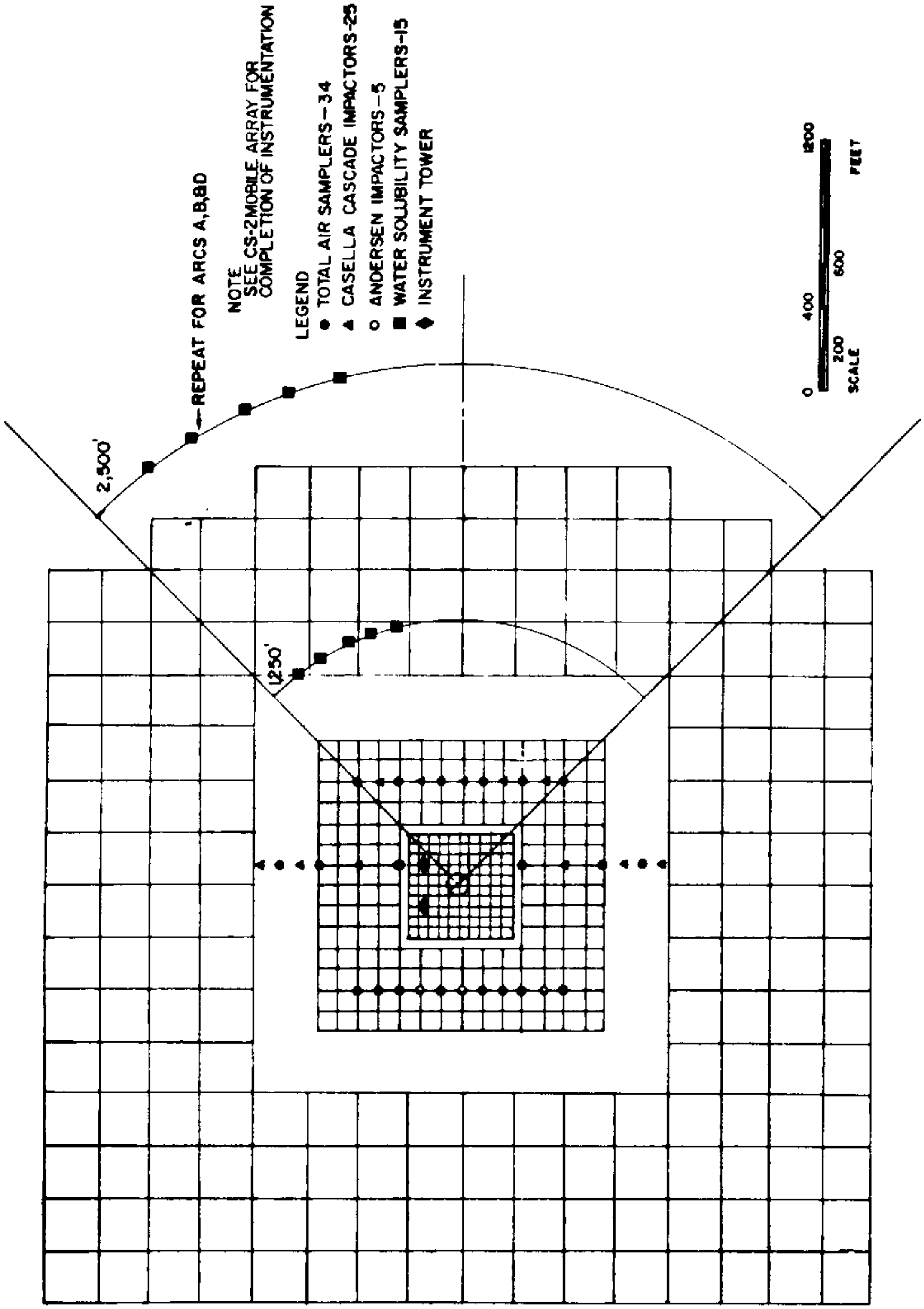


Figure 6.1 CLEAN SLATE No 2 ground zero grid system, showing placement of air samplers.

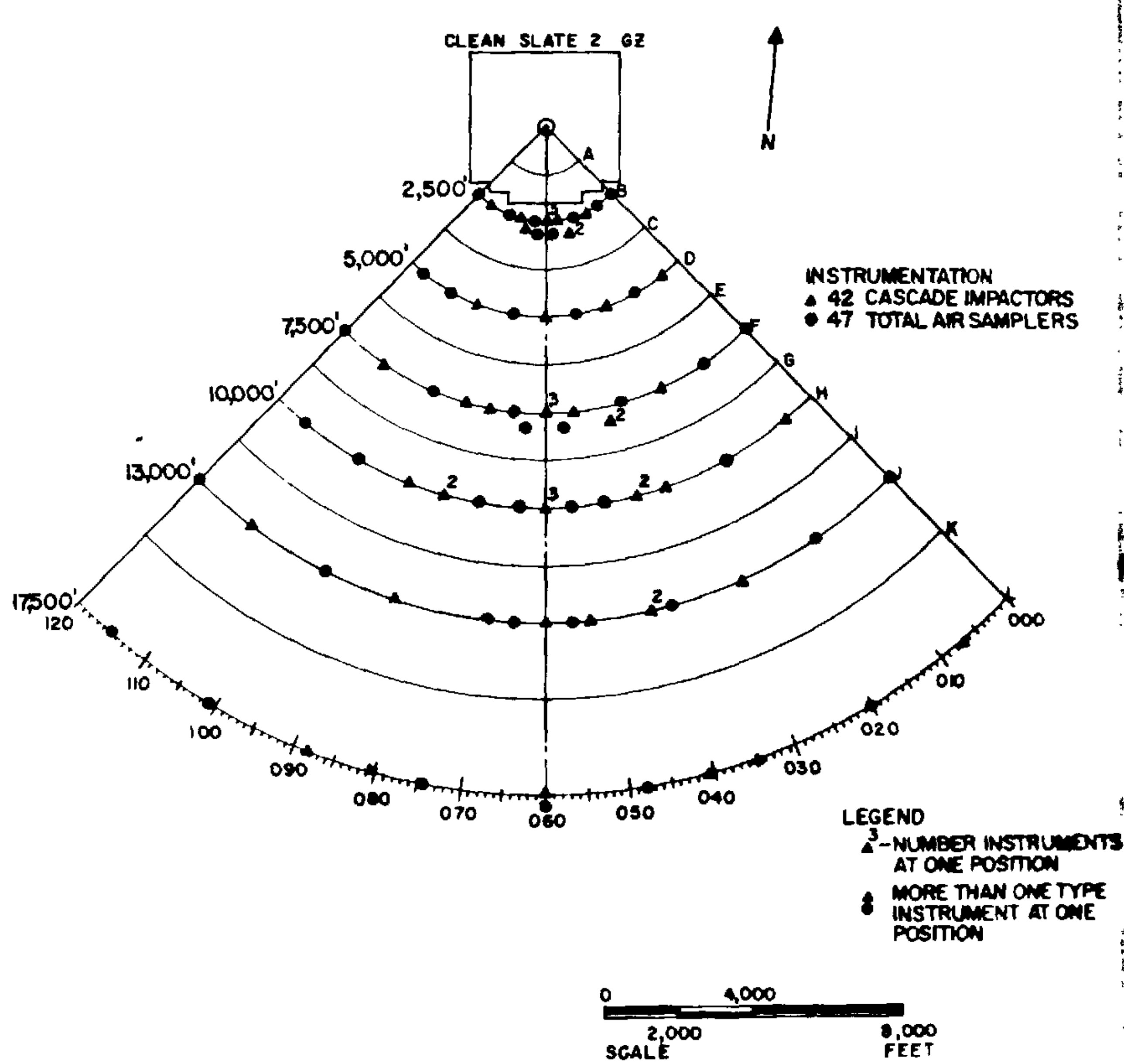


Figure 6.2 CLEAN SLATE No. 2 array, showing placement of fixed array for air samplers.

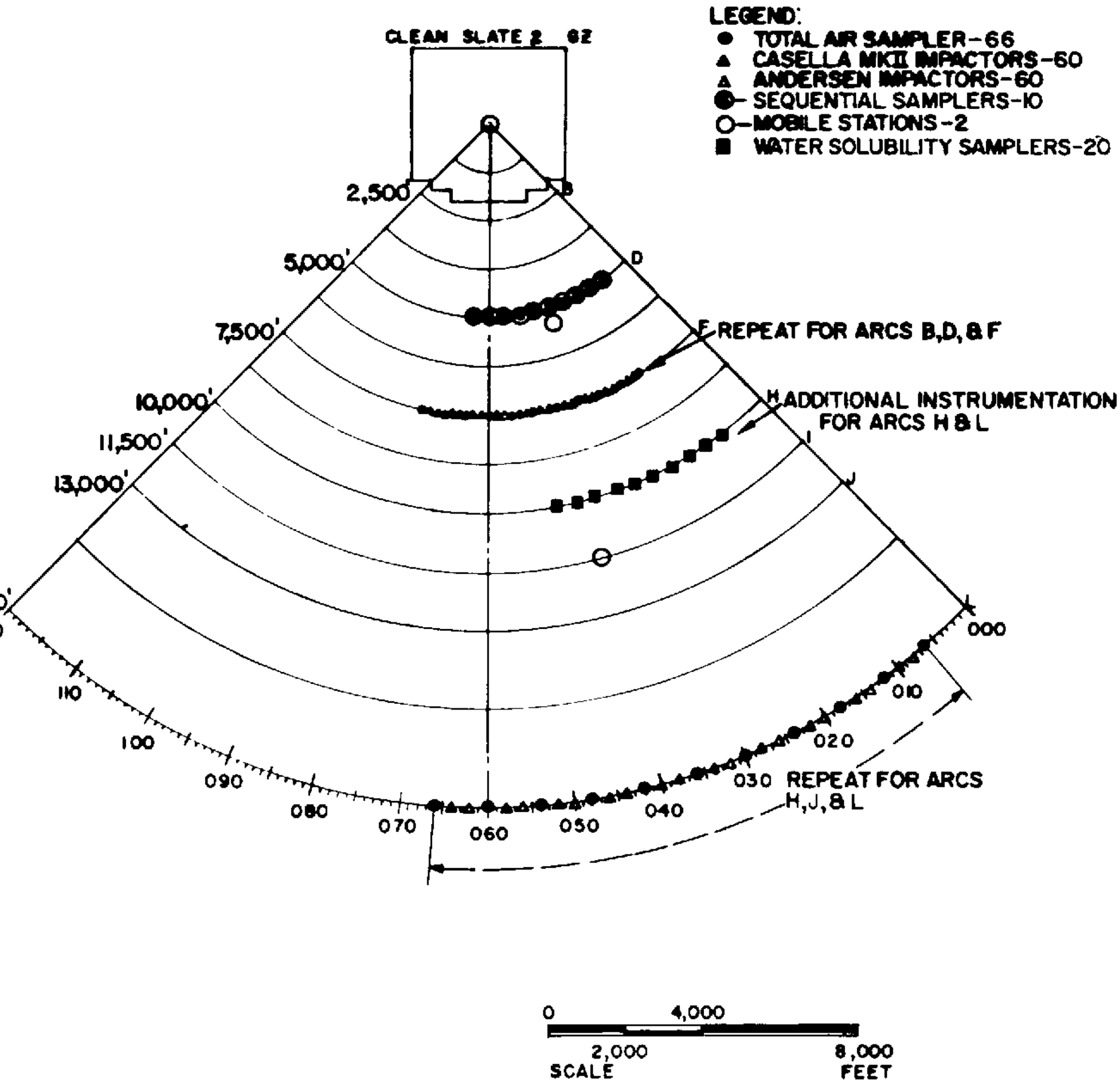
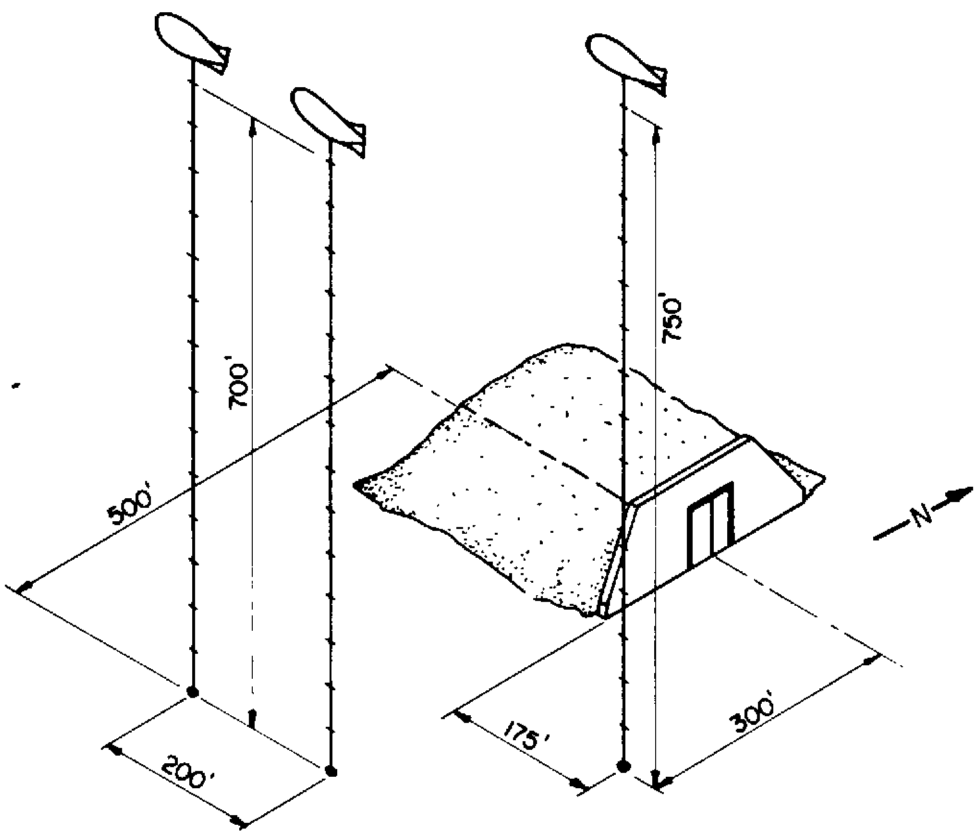


Figure 6.3 CLEAN SLATE No. 2 array, showing placement of movable array for air samplers.



On 700-foot balloons:
Alternating Sticky Cylinders and Discs at 50-foot intervals starting from top with Sticky Cylinder.

On 750-foot balloons: Casella Impactors at 700 feet and 350 feet
Sticky Cylinders at 50-foot intervals.

Figure 6.4 Instrumentation and placement of ground zero balloon array, CLEAN SLATE No. 2.

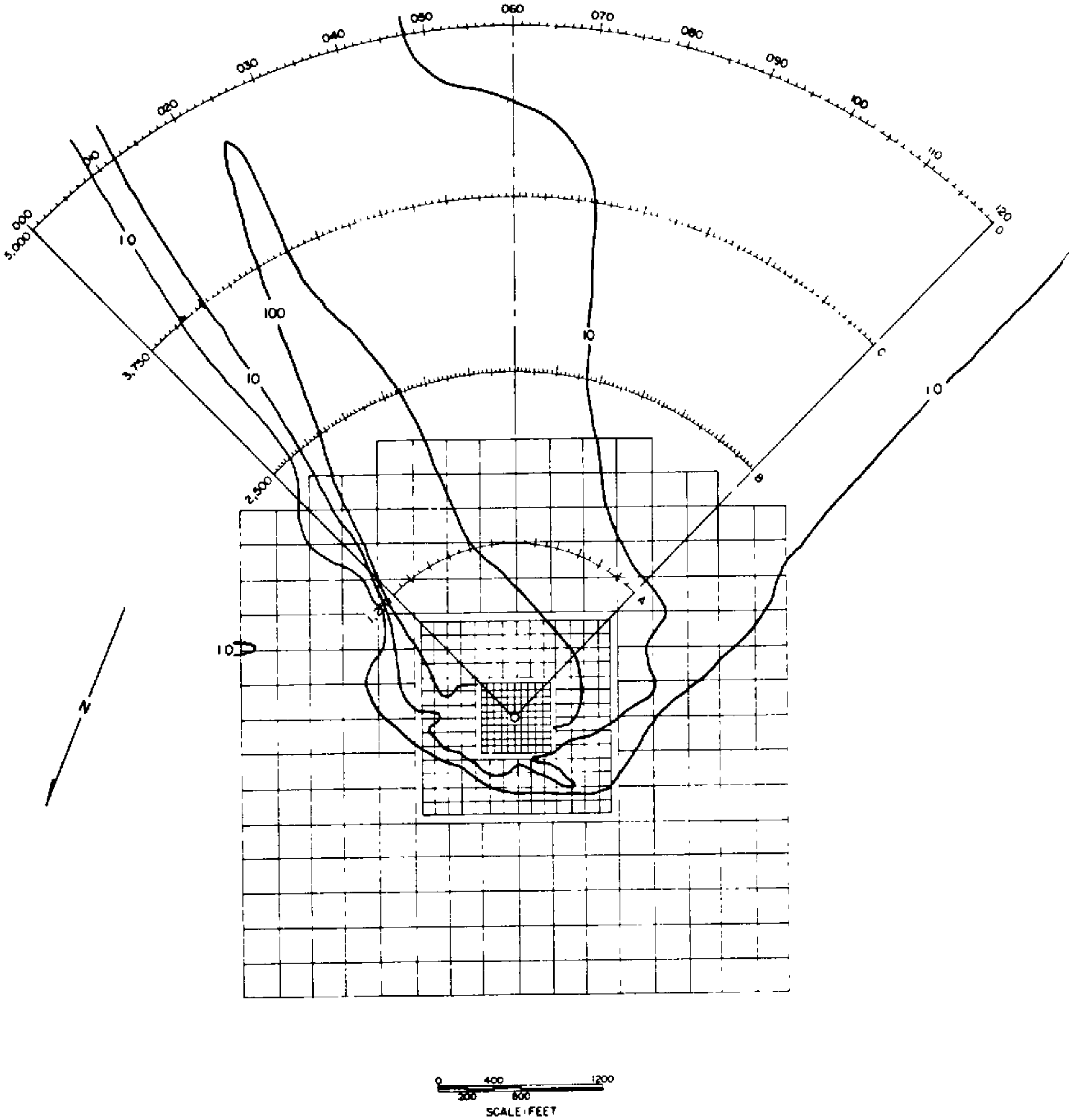


Figure 6.5 CLEAN SLATE No 2 deposition contours by alpha survey in $\mu g/m^2$.

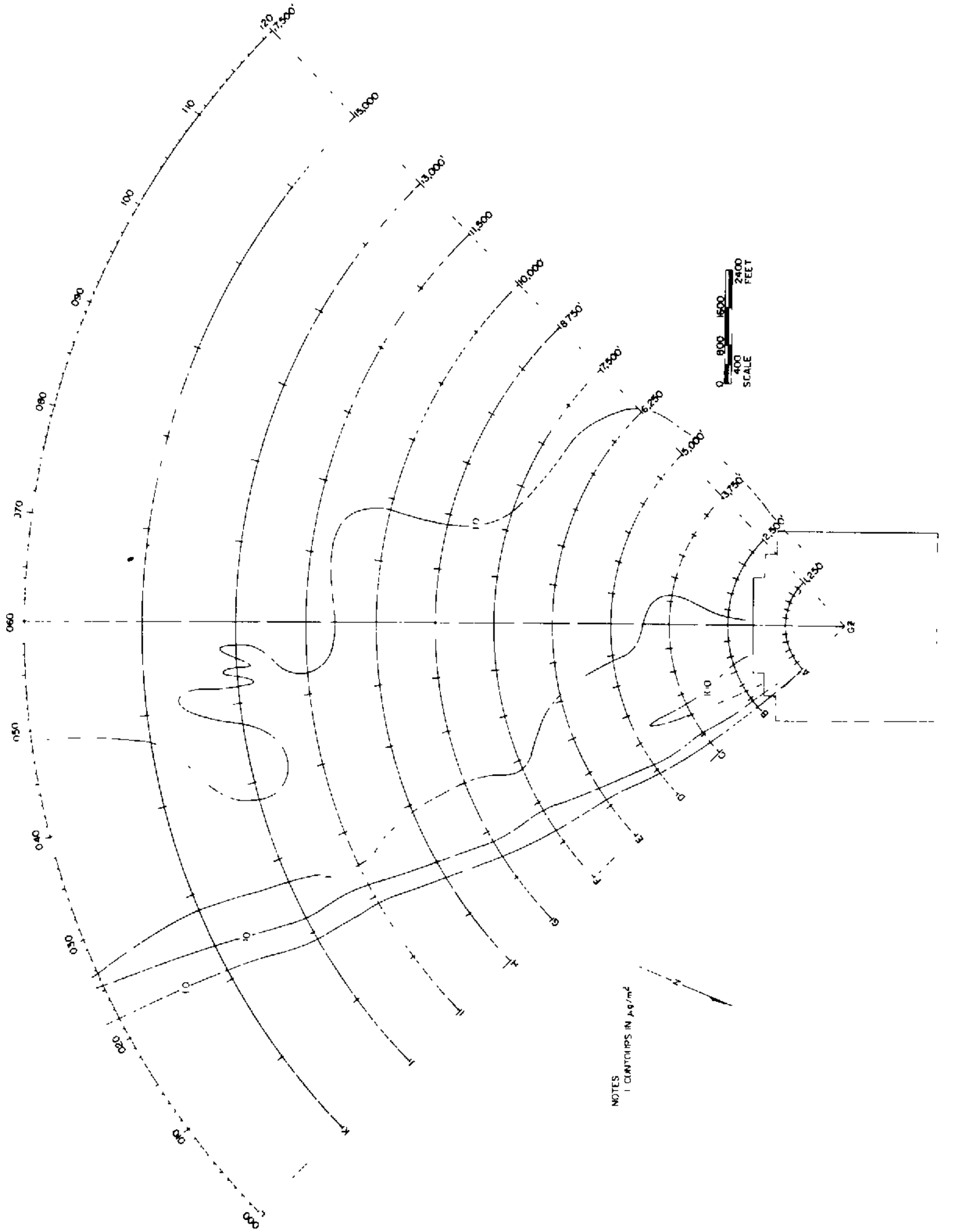


Figure 6.6 Deposition contours by alpha survey in $\mu g/m^2$, **CLEAN SLATE No. 2.**

Figure 6.6 Deposition contours by alpha survey in $\mu g/m^2$, CLEAN SLATE No. 2

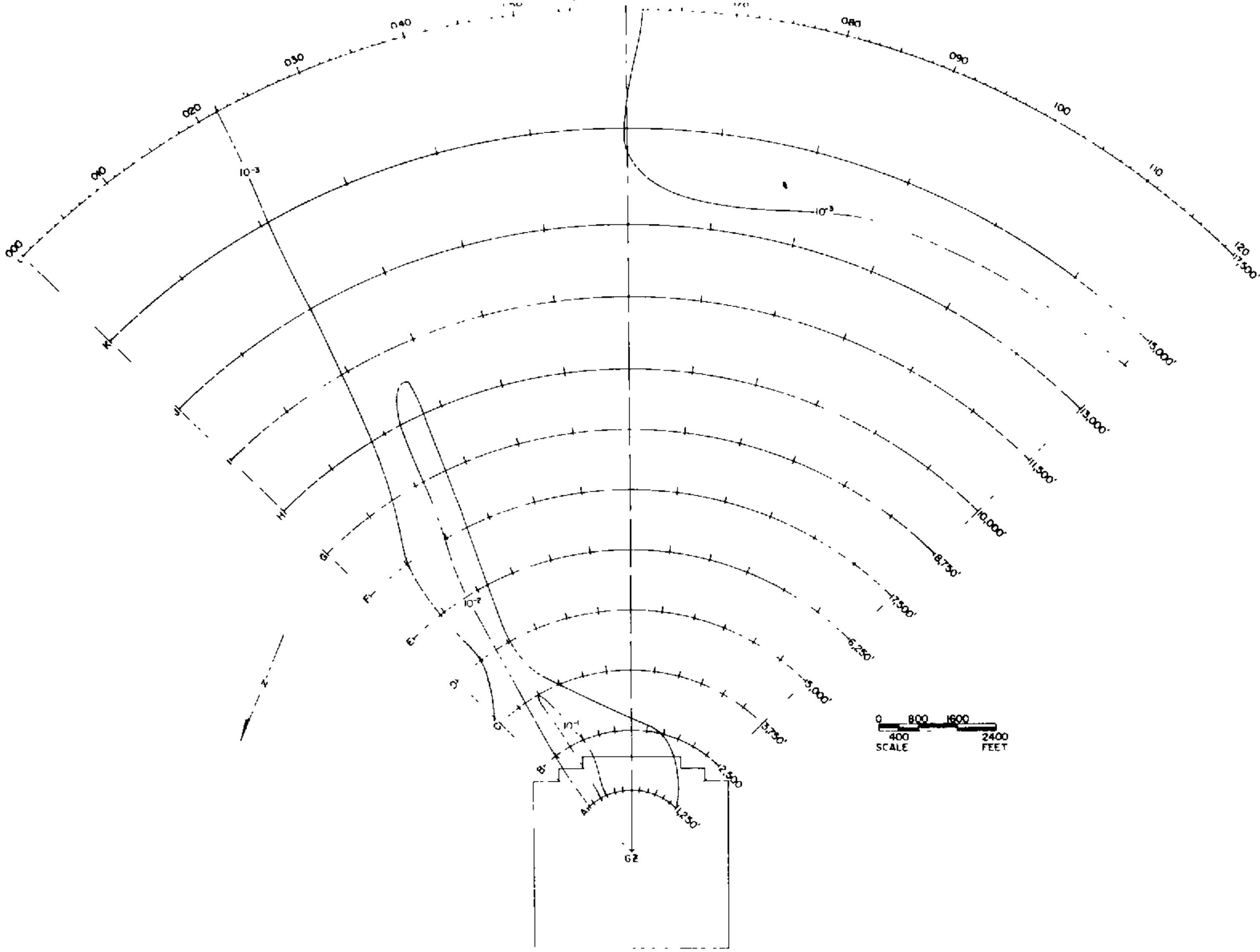


Figure 6.7 Total plutonium (μg) in air sampler uptake during CLEAN SLATE No. 2 cloud passage.

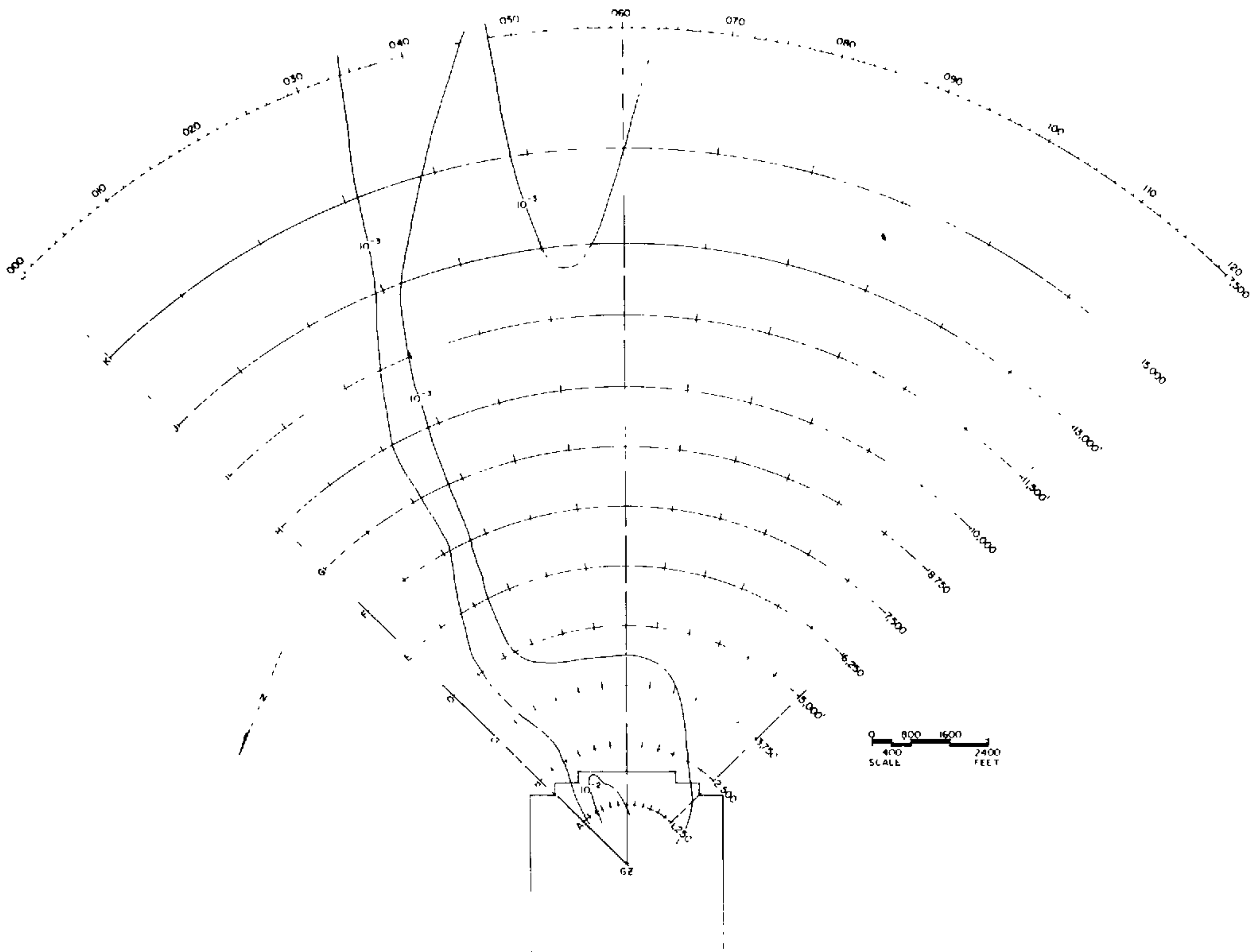


Figure 6.8 Respirable plutonium (μg) in air sampler uptake during CLEAN SLATE No. 2 cloud passage.

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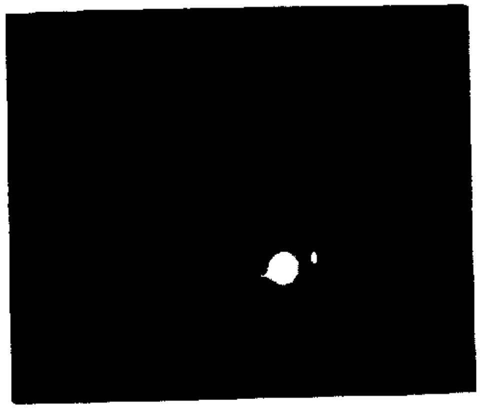
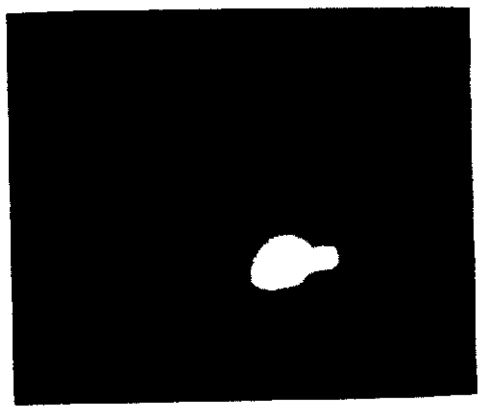
Figure 6.8 Respirable plutonium (μg) in air sampler uptake during CLEAN SLATE No. 2 cloud passage.



H + 1 milliseconds



H + 11 milliseconds

H + 47 milliseconds

Figure 6.9 High-speed CLEAN SLATE No. 2 sequence for 1,500 feet north of ground zero. (Sandia Corporation photos)

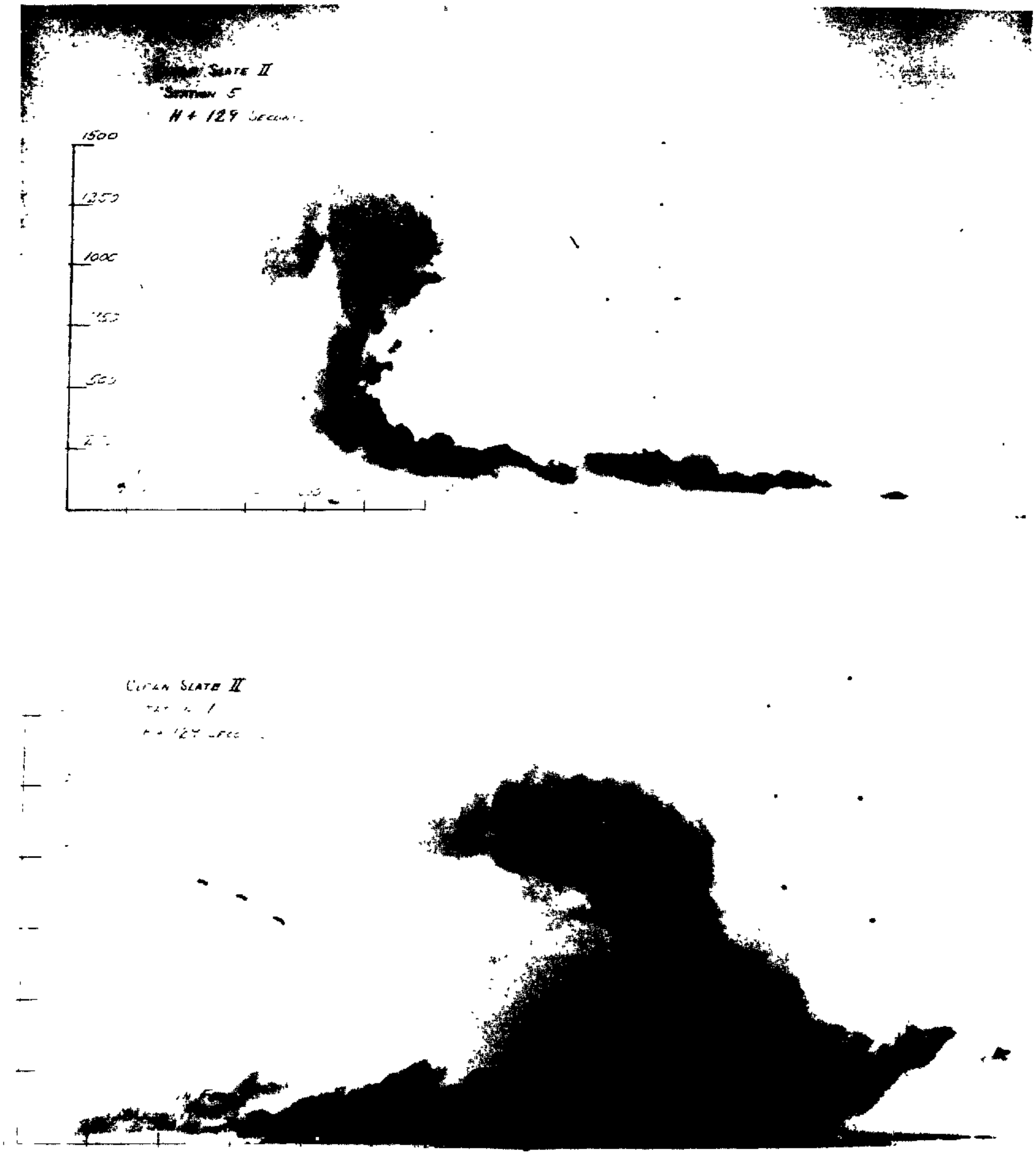


Figure 6.10 Two views of CLEAN SLATE No. 2 cloud at time of balloon curtain intercept. (Sandia Corporation photos)

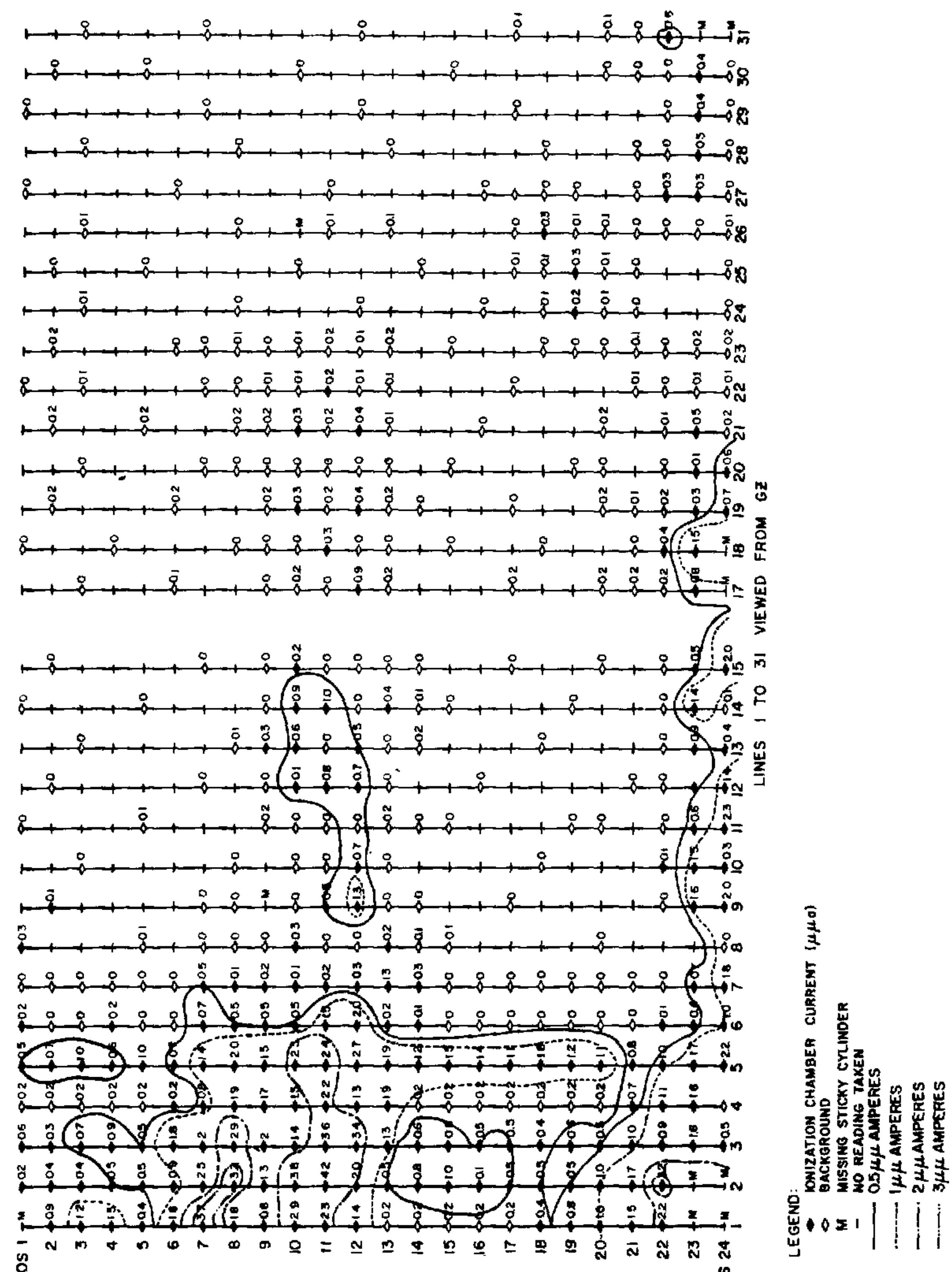


Figure 6.11 Comparative air concentrations measured by sticky cylinder collections on CLEAN SLATE No 2 at 2,500 feet

CHAPTER 7

EVENT CLEAN SLATE NO. 3

7.1 DESCRIPTION OF THE EVENT

7.1.1 Instrumentation. Instrumentation added beyond the basic plan was as follows:

(a) Due to the widespread activity found across the whole 90° arc on CLEAN SLATE No. 2 and the difficulty of positioning the movable array under light wind conditions, it was decided to double the spacing between instruments. The movable array, therefore, ceased to be movable and covered the whole arc with instruments at 3° spacing; some effort was made to interweave movable and fixed instruments (Figures 7.1 and 7.2).

(b) Solubility samples were collected as for CLEAN SLATE No. 2 (Figure 7.2).

(c) Over 130 additional air sampling devices were spread over the array (Figures 7.1, 7.2, and 7.3) and a number were located on the CLEAN SLATE No. 1 array (Figure 7.4) which lay to the south of the CLEAN SLATE No. 3 array. This extended the sampling array by several miles.

(d) Tower-mounted Casella MK II impactors were operated in the fireball zone in the same manner as for CLEAN SLATE No. 2.

(e) Sixteen fallout collector stations had duplicate collectors.

(f) The CLEAN SLATE No. 3 igloo had a second, separate and duplicate compartment (see Figure 2.8 in Chapter 2) for evaluation of blast and accelerative forces communicated to it from the used chamber. This was a non-interfering experiment with measurements (positions and types in Figure 7.5) made by the Naval Ordnance Test Station of China Lake, California. BRL and Wiancko air pressure gauges plus Wiancko accelerometers and earth pressure gauges were used.

7.1.2 Balloon Arrays. Due to circumstances described below, no major balloon curtain was employed.

Two small balloons carrying sticky cylinders and discs were positioned to obtain early samples from the dirt cloud and fireball (Figure 7.6).

7.1.3 Preshot Events. CLEAN SLATE No. 3 was originally scheduled for 0100, 7 June, but due to an unfavorable weather forecast on 5 June, a 24-hour delay was called.

The array was instrumented on 7 June, and the balloon curtain was raised by 0030, 8 June. At 0100, wind directions were suitable but veering steadily. The movable array was, therefore, relocated in the western half of the fixed array. The winds veered off the array before this move was completed. Shortly before first light a hold was called, while cloud-tracking cameras were converted for daylight photography. This was accomplished by 0530, but at this time, the winds backed rapidly to such an extent that the movable array was again wrongly positioned. With the temperature stability rapidly dissipating, the shot was cancelled at 0600; a new H-hour of 0100, 9 June, was set.

This additional 24-hour delay gave sufficient time for the rigging for a second balloon curtain to be completed; two balloons had been inflated. During the afternoon of 8 June, faults in the balloons, coupled with local thunderstorms, caused both balloons to rip.

No further balloons were available within a reasonable time and to avoid a delay of at least two or more weeks, it was decided to fire CLEAN SLATE No. 3 as scheduled if meteorological conditions were good.

7.1.4 Shot Phase. Meteorological conditions appeared to be very suitable early in the evening, but H-hour was delayed in order to ensure persistence in these conditions. At 0330, 9 June 1963, CLEAN SLATE No. 3 was fired with mean wind speeds within the cloud height of approximately five knots. The degree of wind shear was variable but amounted to some 45°, the majority of which was in the upper part of the cloud. A strong inversion of some 5.5° C had formed to a height of 1,000 feet.

7.1.5 Postshot Phase. Alpha survey and sample recovery were completed under good weather conditions.

The 60-foot tower in the fireball zone was destroyed, but samplers were recovered reasonably intact so the samplings will be analyzed. The 30-foot tower was relatively undamaged. Five of the twelve incremental fallout samplers failed to operate correctly to some degree. With these exceptions, all instrumentation operated satisfactorily.

7.2 RESULTS

7.2.1 Alpha Survey. The total alpha survey was completed satisfactorily. Deposition patterns inferred from the survey are shown in Figures 7.7 and 7.8. More detailed results are tabulated in Appendix F.

7.2.2 Airborne Concentrations. Total and respirable airborne concentrations were assessed as before and are shown in Figures 7.9 and 7.10.

7.2.3 Cloud Concentrations and Dimensions. Photographs of the cloud at H+129 seconds appear in Figure 7.11. In Figure 7.12, three frames from high-speed movie coverage of the bunker are presented. Of course no direct determinations of the cloud concentrations will be possible due to the absence of balloon curtains.

7.3 DISCUSSION

The readiness of riggings for two full balloon curtains for the first time in Operation Roller Coaster followed by a two-balloon loss was probably the most severe setback and disappointment faced in the entire field operation. As in CLEAN SLATE No. 2, there must be heavy reliance upon the excellent ground level measurements coupled with careful computation from the mathematical cloud modeling techniques (Appendix N). The extension of the air sampling network onto the CLEAN SLATE No. 1 grid and environs became more important than when conceived. Quantification of material deposited farther downwind obviously helps the plutonium accountancy. More important, its characterization will permit more accurate inference of the particulate spectrum of the source aerosol, of which direct measure was denied with the loss of balloons.

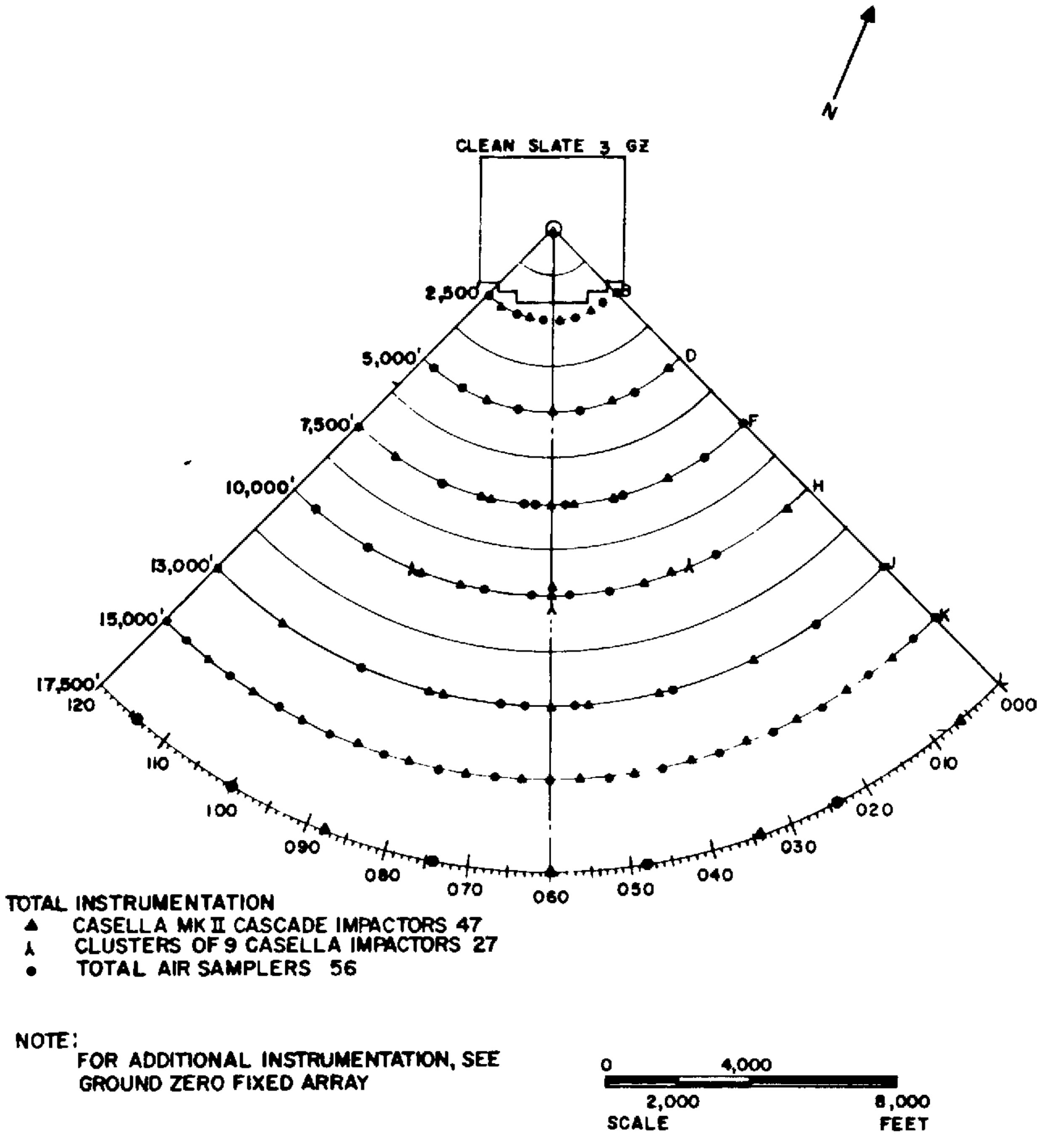


Figure 7.1 CLEAN SLATE No. 3 array, showing placement of fixed array for air samplers.

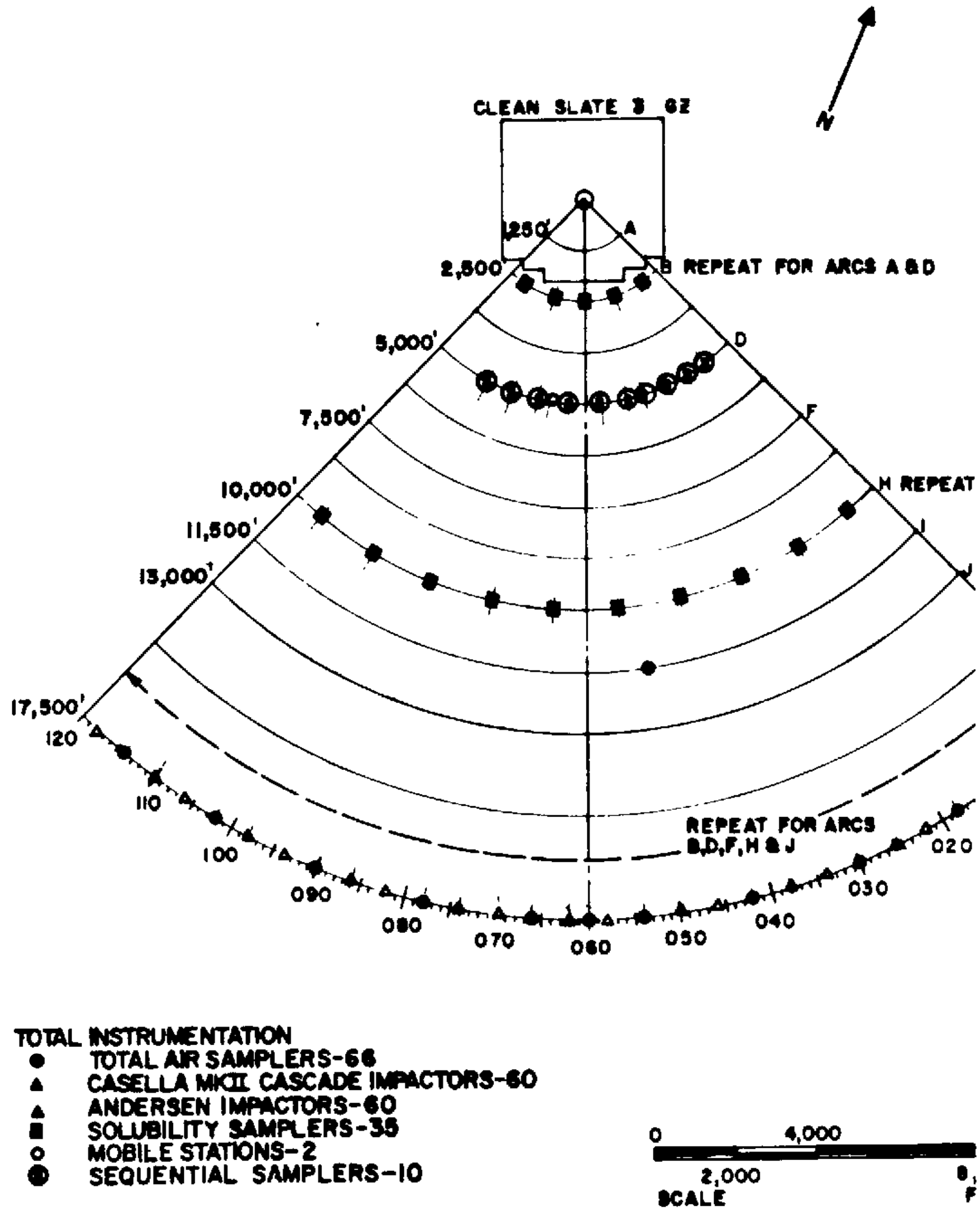


Figure 7.2 CLEAN SLATE No. 3 array, showing placeme of movable array for air samplers.

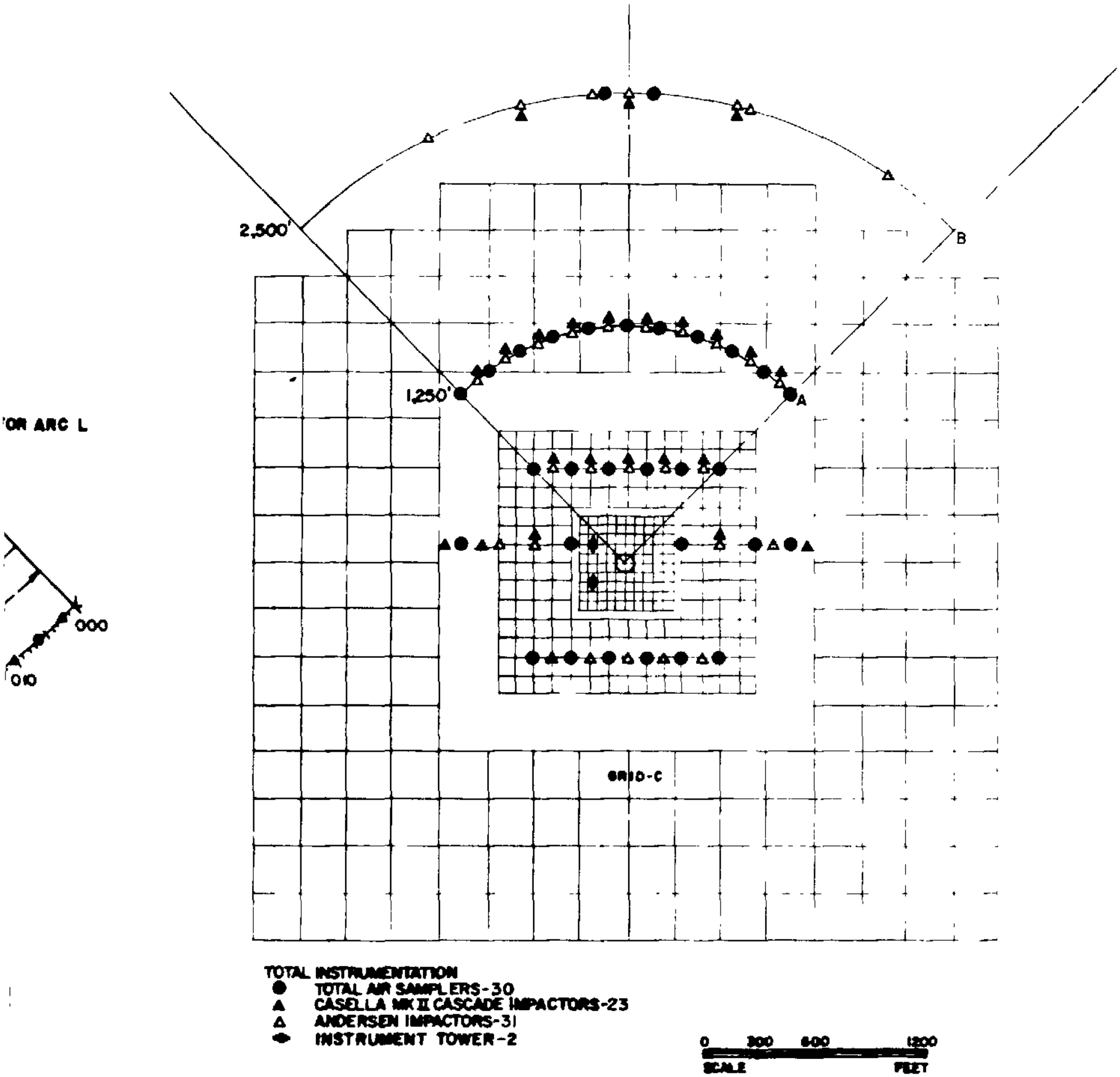


Figure 7.3 CLEAN SLATE No. 3 ground zero grid system, showing placement of air samplers.

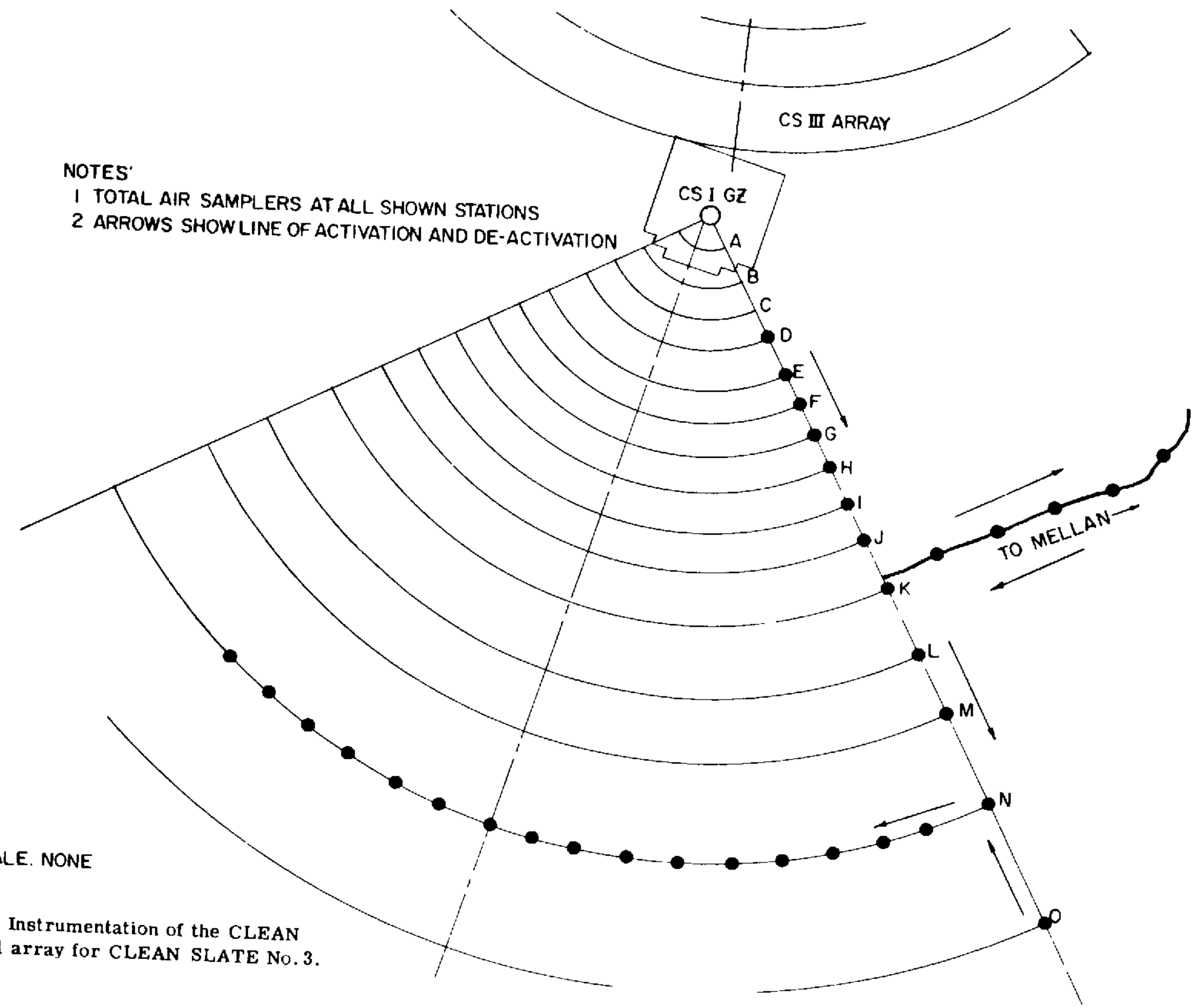
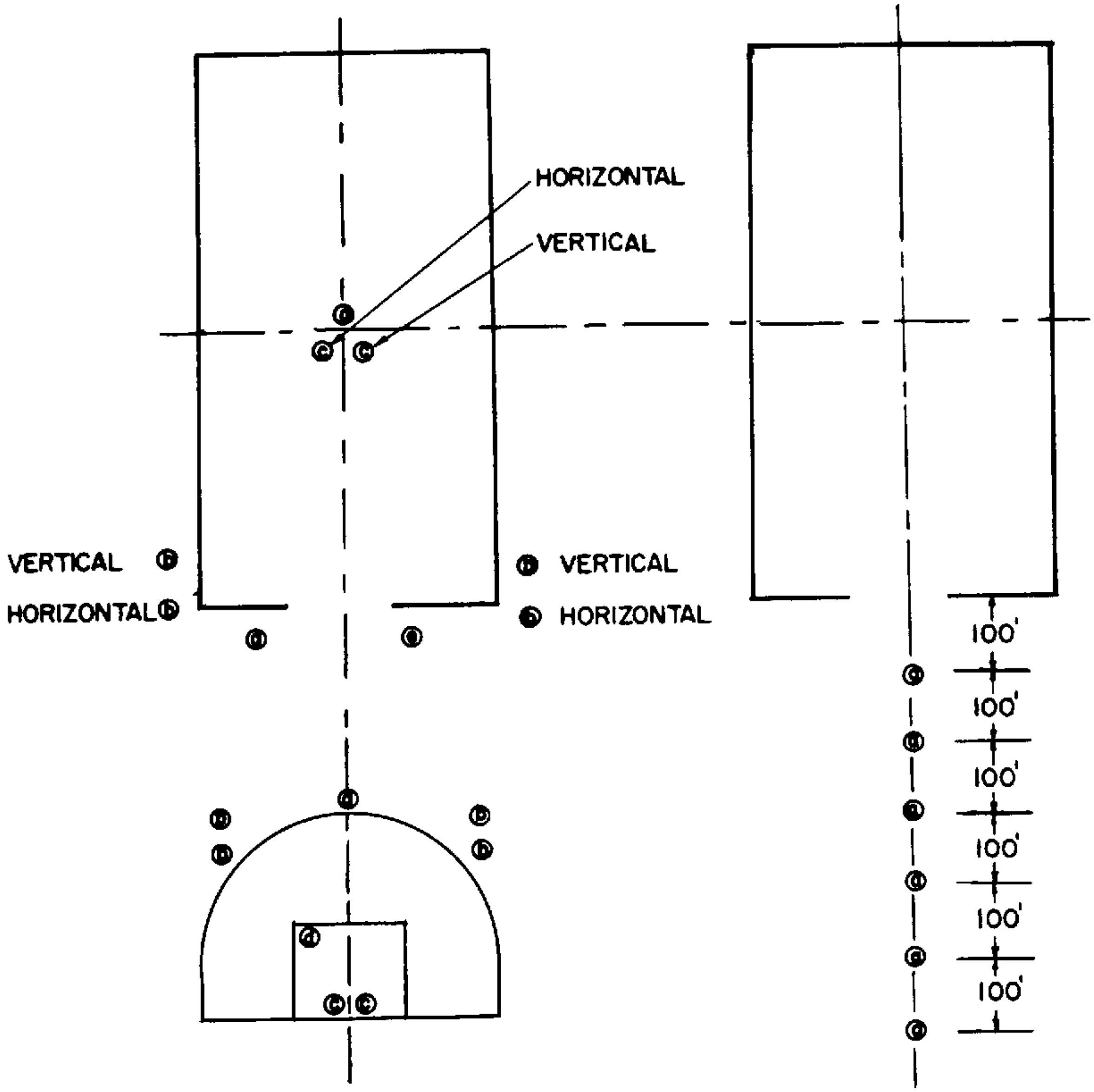
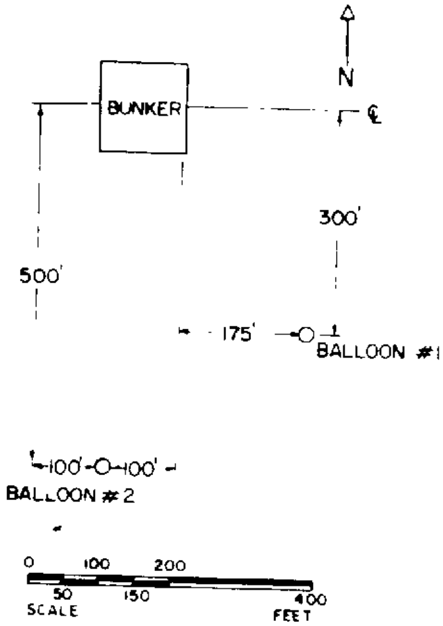


Figure 7.4 Instrumentation of the CLEAN SLATE No. 1 array for CLEAN SLATE No. 3.



NOTES:
1. THE LETTERS REFER TO THE INSTRUMENTS LISTED IN PARAGRAPH II 10
2. SCALE, NONE

Figure 7.5 Placement of pressure and acceleration instrumentation in and around the receptor igloo on CLEAN SLATE No. 3.



POSITION OF INSTRUMENT	BALLOON #1	BALLOON #2
1	SC	SC
2	SC	SP
3	SC	SC
4	SC	SP
5	SC	SC
6	SC	SP
7	SC	SC
8	SC	SP
9	SC	SC
10	SC	SP
11	SC	SC
12	SC	SP
13	SC	SC
14	SC	SP
15	SC	—

NOTE
POSITIONS 14 & 15 LOCATED 10' ABOVE GROUND

SC - STICKY CYLINDER
SP - STICKY PLATE

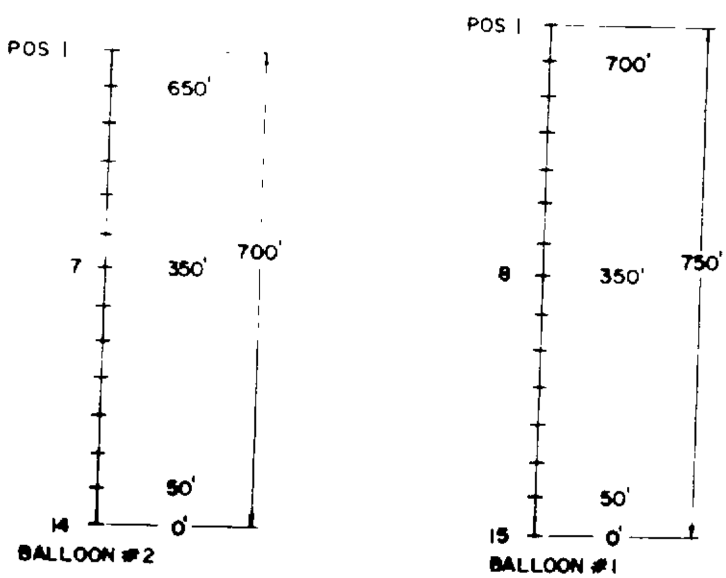


Figure 7.6 Instrumentation and placement of ground zero balloon array, CLEAN SLATE No. 3.

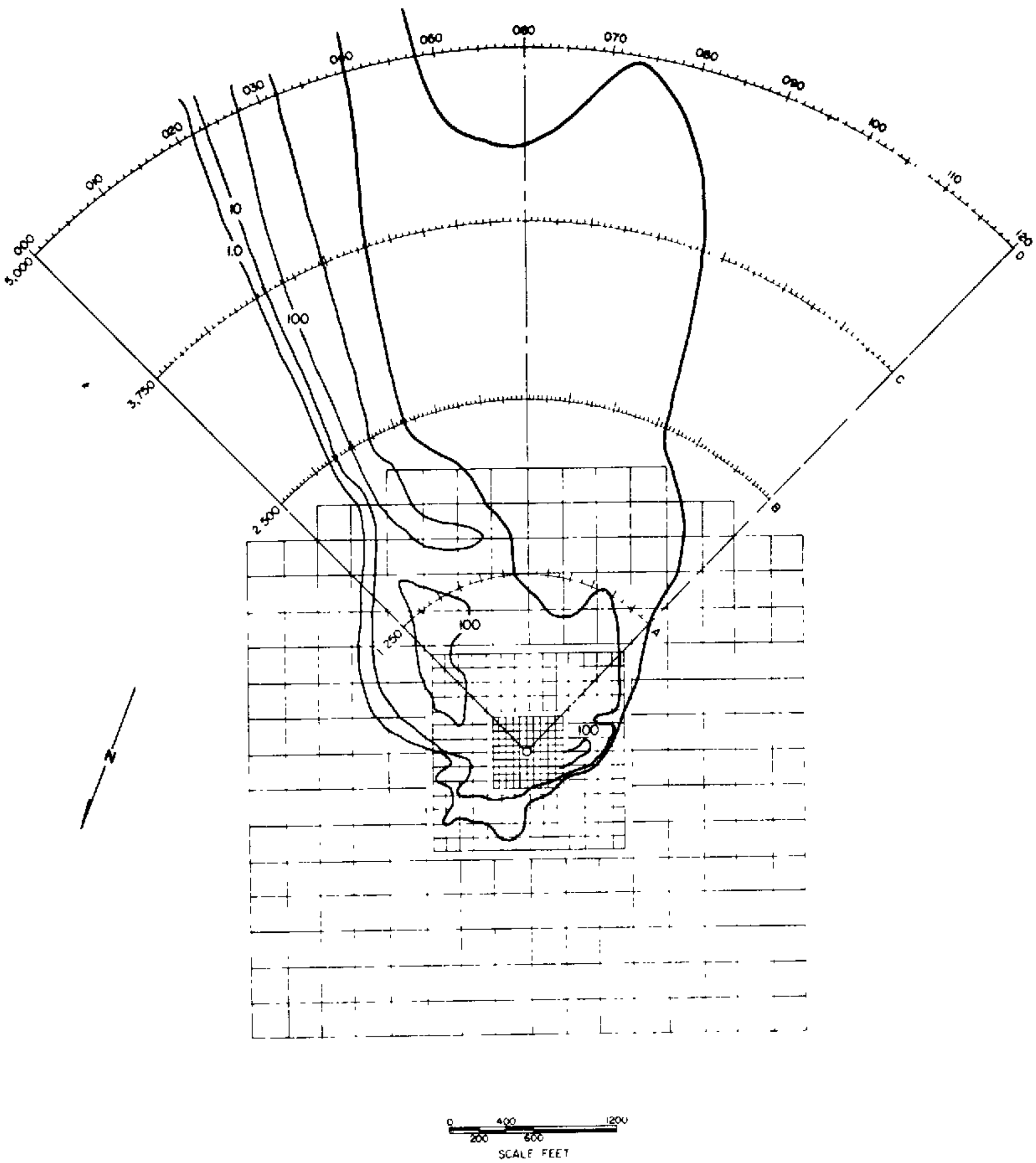


Figure 7.7 CLEAN SLATE No 3 deposition contours by alpha survey in μg/m²

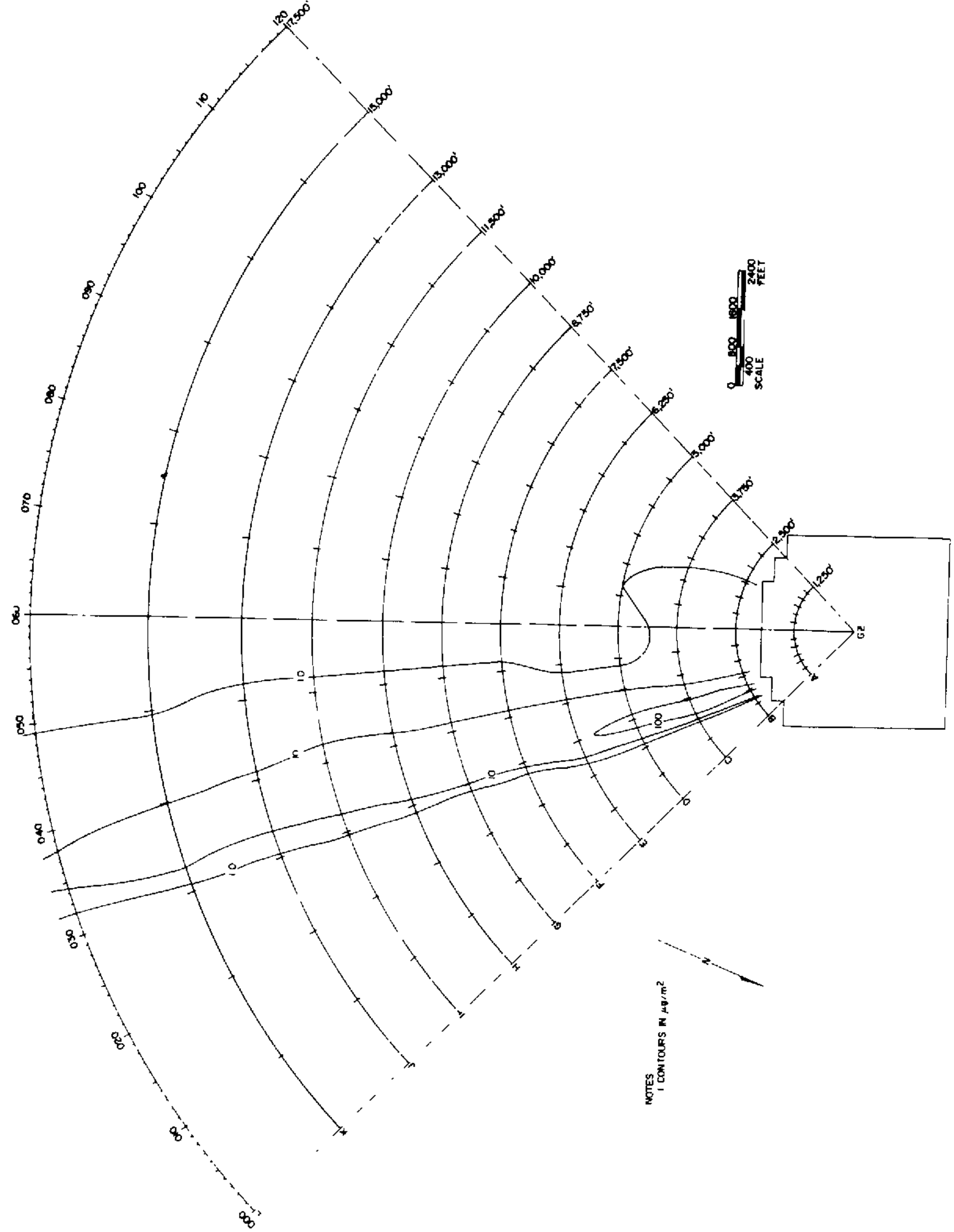


Figure 7.8 Deposition contours by alpha survey in $\mu g/m^2$, CLEAN SLATE No. 3.

Figure 7.8 Deposition contours by alpha survey in $\mu g/m^2$, CLEAN SLATE No. 3.

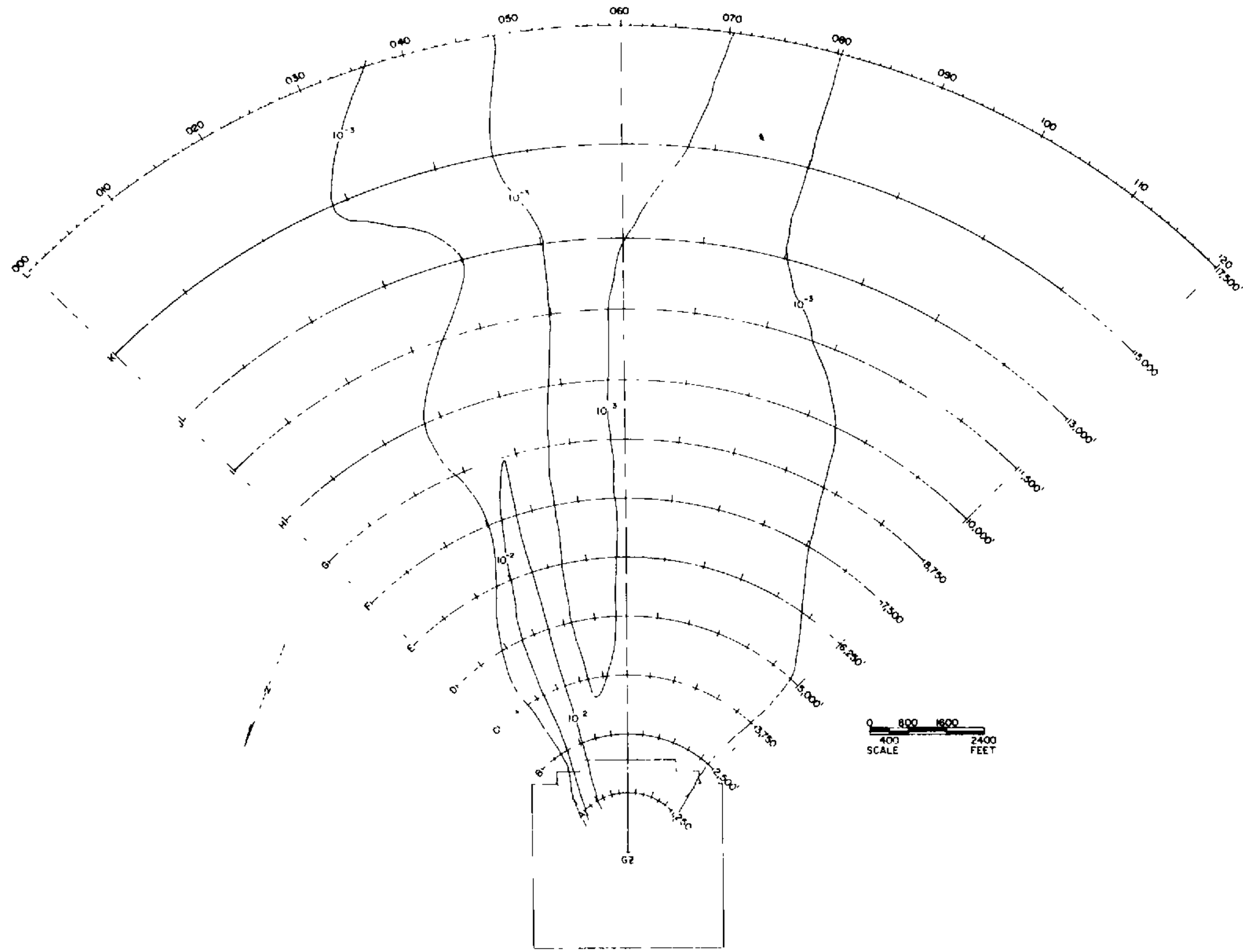


Figure 7.9 Total plutonium (μg) in air sampler uptake during CLEAN SLATE No. 3 cloud passage.

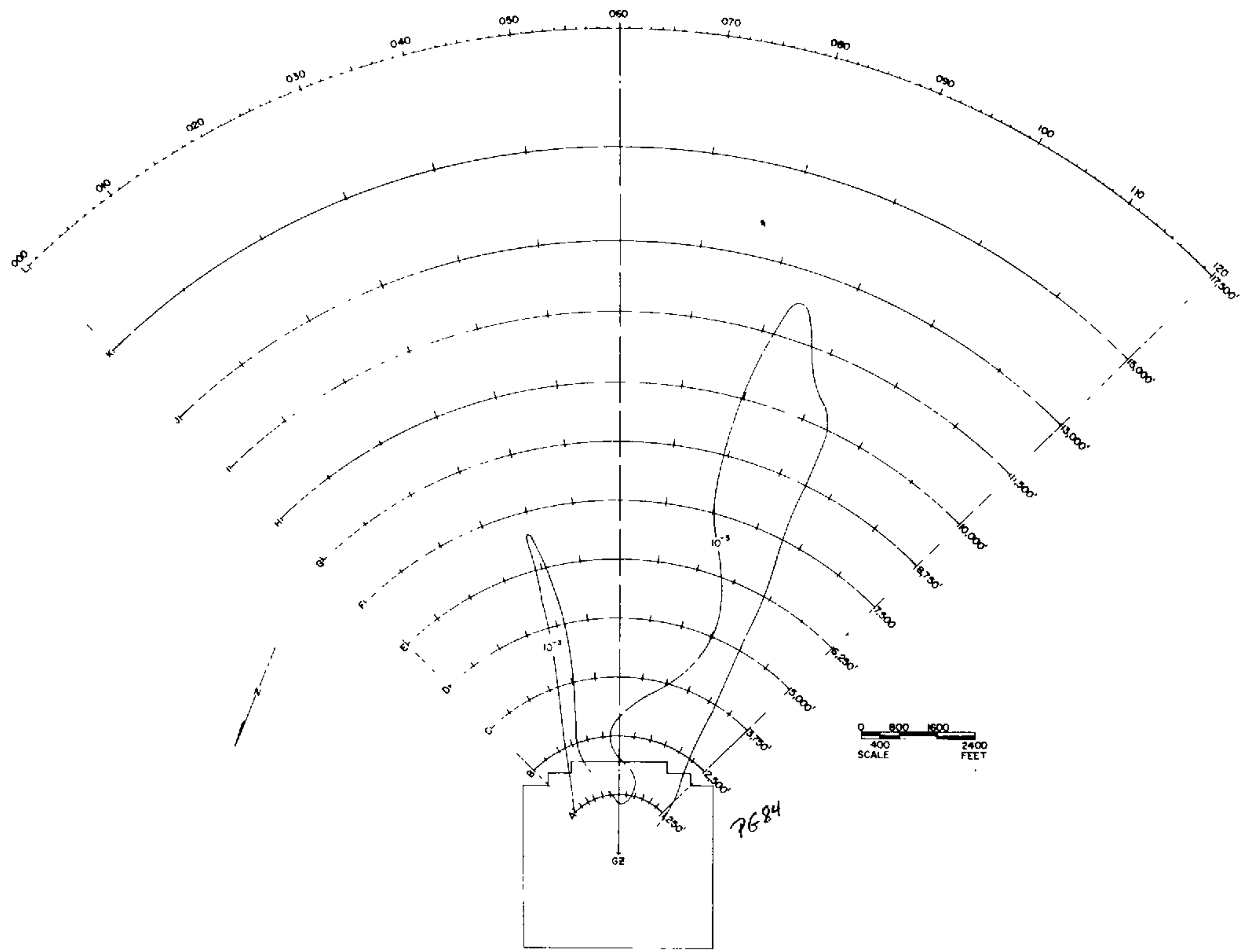


Figure 7.10 Respirable plutonium (ug/m) in air sampler uptake during CLEAN SLATE No. 3 cloud passage.

Respirable plutonium (ug/m) in air sampler uptake during CLEAN SLATE No. 3 cloud passage.

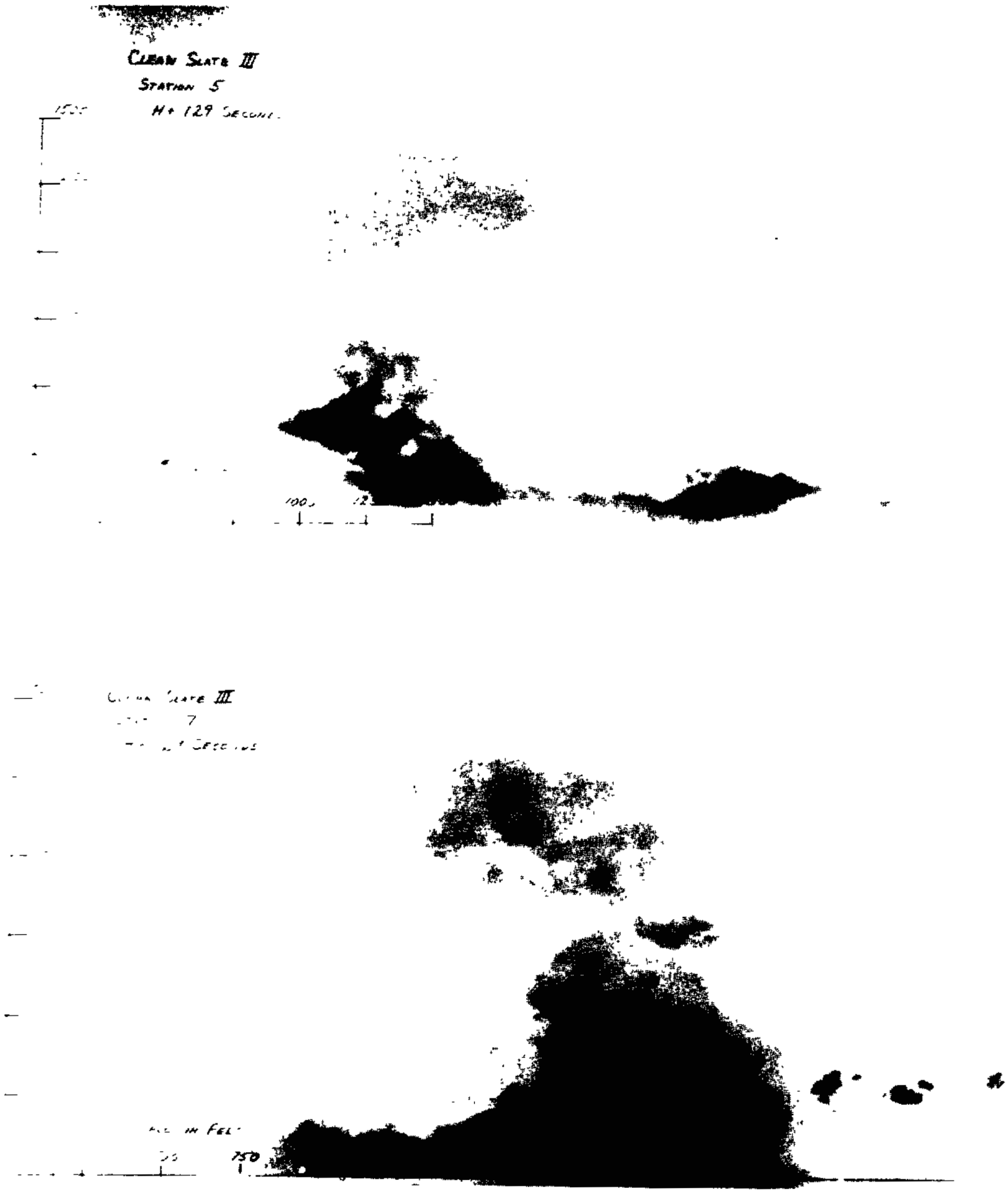
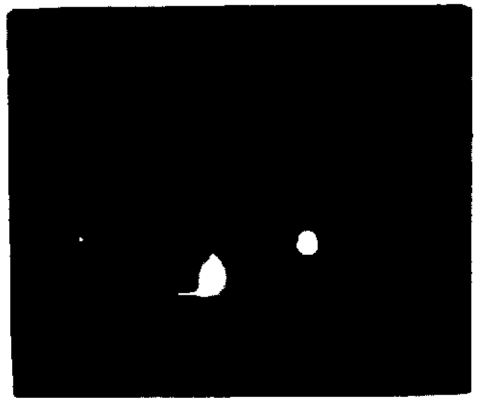
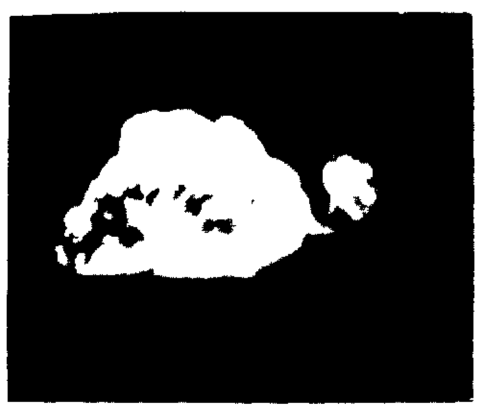


Figure 7.11 Two views of CLEAN SLATE No. 3 cloud at time of balloon curtain intercept. (Sandia Corporation photos)



H + 1 millisecond

H + 11 milliseconds



H + 47 milliseconds

Figure 7.12 High-speed CLEAN SLATE No. 3 sequence for 1,500 feet north of ground zero. (Sandia Corporation photos)

CHAPTER 8

GENERAL CONCLUSIONS AND PROSPECTUS

8.1 INTERPRETIVE BASIS

Conceptually, the Roller Coaster experiment comprised four parts, all to be carefully intercompared -- a one-unit open shot, a multi-unit open shot, and two multi-unit shots in storage structures. Different environs, different high explosive yields, and different degrees of physical confinement of the explosion complicate the intercomparison. Ideally, each set of results is to be expressed in terms of the radiological hazard to man. To start, the source plutonium (and uranium) must be accounted for and this is a difficult thing to do even with measurements over tens of square miles (DOUBLE TRACKS). Then, detailing plutonium found into particle size classes is necessary since the radiological hazard in this case is almost solely inhalation incurred. Designation of respirable size or respirable size range is not assuredly simple; particle homogeneity, density, frangibility, and shape can really influence respirability. Clearly, characterization of particles, especially in these particulars, is essential. Chemical classification is similarly mandatory, primarily with respect to likely solubility in body fluids. Finally, animal uptake, retention or clearance, migration, and metabolism or simple excretion are climactic factors in the radiological hazard from aerosolized plutonium.

It may well turn out that with quantification and physical and chemical characterization of the plutonium-bearing particles, these biological factors and thereby the hazard can be satisfactorily estimated. Such estimates are even more acceptable if they have been verified by field exposure of animals to the carefully measured aerosol. To wit, Roller Coaster experimentation included a sizable, three-species animal exposure program.

From the foregoing, it is clear that the copious data gathered must be precisely reduced and interrelated before final conclusions may be attempted. Recognition and acceptance of these conclusions must follow a process of weighing and refining over a period of months of active evaluation and consideration. Meanwhile, qualitative, even semi-quantitative observations are possible as are statements of the completeness and quality of data gathered.

8.2 PLUTONIUM ACCOUNTANCY

Rather incomplete plutonium accountancy appears evident from first integrations of ground level measurements by alpha survey. Of course, alpha survey meters give results of variable quality as age of fallout, most abundant particle size present, and nature of surface monitored, vary. Areas enclosed by 1, 10, 100 μgm deposition isopleths drawn from the alpha survey data are given in Table 8.1; the same table lists an estimate of the plutonium thereby accounted for. This assessment has had two factors of two applied. The first two tries to compensate for greater intensity everywhere within the contour than on it. The second is an average correction found necessary when some autoradiographic and alpha survey instrument readings of the same surfaces were compared across a DOUBLE TRACKS arc (Appendix M). The overall multiplier of four has much of surmise in it so one must take the answers as instructive, indicative of order of magnitude only. GZ area entries are unenlarged quantities since they were inferred principally from gamma survey measurements of both plutonium and americium.

More comprehensive accountancy will grow from autoradiography of planchets and radiochemical analysis of sticky papers both from Project 2.3. The promise, from best ground measurements, of accounting for a much higher percentage of the released amount than Table 8.1 shows is believed to be small. On DOUBLE TRACKS and CLEAN SLATE No. 1, there is excellent chance of nearly complete accountancy. Extrapolating from the portion caught by the curtain on CLEAN SLATE No. 2 should, with the good photography of the visible cloud, produce a credible accounting too. The variation in particulate spectrum with downwind distance from GZ (on all shots) should imply the nature of the source spectrum and in so doing allow deduction of original source strength and the aerodynamic character of particles flying beyond instrumented areas. On CLEAN SLATE No. 3, this will be the major accountancy determinant since no balloon data were obtained.

8.3 PARTICULATE SPECTRA

Air sampling, really extraction of particulate matter from air, near the ground and on the balloon curtain(s) was done in most cases with cascade impactors. Thus, most samples or particulate extractions are directly indicative of mass or alpha activity divisions among several (five or six) size fractions. Unfortunately, the information reported from field counting has variable quality. Large particle activities (first and second sampler stages) are underestimated because of self shielding. Smaller particles are implicitly more accurately counted but all but the last cascade impactor stages were coated to get high particle sticking coefficients; variable masking and significant masking is probable. Final, or millipore filter, stages give the most likely results from simple counting. With these provisos, the air sampling results may be studied for first indications. Obviously, the picture possible must be considered very incomplete.

Ultimately, however, the accurate assay of these samples (for plutonium content per stage and for the (Projects 2.6a,b,c) character of individual particles or subgroups of the particles) probably will be the most important single element in quantifying the radiological hazard to man.

8.4 BIOPHYSICAL FACTORS

Field positions of the three species of animals were intermeshed during exposure and countable air sample collections were found throughout the array. The inadequacies of straight counting of impactor stages are exactly those just mentioned, even more extreme perhaps because respirability is the added factor of immediate importance. Respirable or smaller particles occur in large concentration near the ground only near GZ and are contributed almost totally from the cloud stem which has the smallest lateral extent. Thus, the cross-wind gradient is extremely sharp, much narrower and sharper than the activity deposited on the ground. Hopefully, enough animals of all three species inhaled and retained enough plutonium to permit unequivocal initial uptake data and meaningful metabolism information, both early and long term (sheep only). Only the precise answers of radiochemistry can substantiate the real degree of success in this experiment.

8.5 HAZARD EVALUATION

Patently, the radiological hazard to man from the several kinds of non-nuclear weapon accidents typified by the four Roller Coaster events was the principal prompting of the Operation. First, and simplest (though not simple) is the DOUBLE TRACK situation. One can reckon the hazard from the physical and chemical data above via procedures normally employed in restricting inhalation of alpha emitters in industry. The biophysical or biomedical experiments should provide a separate answer for extrapolation to man. Ideally, these two means to the same answer can be reconciled. This done, data from the other shots will be more defensibly translated into radiological hazard terms, also. The addition of animals to CLEAN SLATE No. 2 will provide an additional and key point of correlation. Again, measurable but low counts were registered by air samples on the animal trailers. The true measure (radiochemical) will be higher and can be much higher than these values.

The physical measurements of fallout and air concentration (gross and size-separated) seem to have been consistently good. Although the ballon curtain was hit solidly, but two in three times, the instrumental ground area was not missed laterally on any shot. Admittedly, on CLEAN SLATE No. 2 the close-in pattern (inside 8000 ft.) at the $1 \mu g/m^2$ level as deduced from alpha survey appeared to exceed the 90° sector of the array. Even so, the measurements encompassed nearly the entire area possible.

Thus, a very high degree of success can be claimed for the overall list of experiments attempted. As important as the direct understanding of conditions which obtained for each of the shots fired, is the ultimate induction from experimental results to more general terms of description. It was with this in mind that immense care was taken in making extensive micro meteorological measurements. Existing US and UK cloud models have been exercised already on the measured meteorology of each shot. The resulting ground- and air-concentrations calculated (Appendix N - Volume 3) compare favorably with their preliminary counterparts from survey meter data and field counted air samples. Similar comparisons will be made with more accurate data and with better information fed into the cloud models on actual particle size and its relation to activity.

Improvements in the ability to forecast fallout and respirable plutonium for any reasonable weather situation seem assured. Furthermore, the influence of storage structures of the type tested will be believably assessible for the first time. More general appreciation of hazard modification, by storage structures of more arbitrary character, is anticipated.

TABLE 8.1 INTEGRATIONS OF ALPHA AND GAMMA SURVEY OF GROUND DEPOSITION OF PLUTONIUM

Shot	Deposition Contour ($\mu g/M^2$)	Area Enclosed (M^2)	Inferred Plutonium* Contained (gm)
DOUBLE TRACKS	GZ Area	Steel Plate	21
	1	3.9×10^7	156
	10	7.1×10^5	28
	100	2.3×10^3	1
			206 Total
CLEAN SLATE NO. 1	GZ Area	---	---
	1	8.0×10^6	32
	10	7.4×10^5	30
	100	7.3×10^3	3
			65 Total
CLEAN SLATE NO. 2	GZ Area	2.9×10^3	39
	1	9.4×10^6	38
	10	2.4×10^6	96
	100	2.5×10^5	100
			275 Total
CLEAN SLATE NO. 3	GZ Area	1.2×10^4	46
	1	4.8×10^6	20
	10	2.0×10^6	80
	100	1.4×10^5	56
			202 Total

*i.e., four times the integrated value from alpha survey contours.

REFERENCES

1. "Research Program for Evaluation of Storage, Handling, and Transportation Criteria for Plutonium-Bearing Weapons, Operation Roller Coaster"; 15 January 1963, Secret Restricted Data.

Number of Copies	
	ARMY ACTIVITIES
1	Chief of Research and Development, Department of the Army, ATTN: Atomic Division, Washington 25, D.C. 20310
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2	General Dynamics Corporation, Nuclear Design and Operations Division, Grants Lane, ATTN: William T. Price, Fort Worth 1, Texas
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5	Director, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, New Mexico
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1	ATTN: Rexford Sherwood
5	U.S. Atomic Energy Commission, San Francisco Operations Office, 2111 Bancroft Way, Berkeley 4, California
5	U.S. Atomic Energy Commission, Nevada Operations Office, P.O. Box 1676, Las Vegas, Nevada

5 U.S. Atomic Energy Commission, Albuquerque Operations Office, P.O. Box 5400, Albuquerque, New Mexico

2 U.S. Public Health Service, c/o U.S. Atomic Energy Commission, P.O. Box 1676, ATTN: John Coogan, Las Vegas, Nevada

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1 Chicago Operations Office, Division of Health and Safety, 9800 South Cass Avenue, Argonne, Illinois

2 Hazelton Nuclear Science Corporation, 4062 Fabian Way, ATTN: Roller Coaster Project Officer, Palo Alto, California

1 Chairman, Armed Services Explosives Safety Board, Building T-7, Gravelly Point, Washington 25, D.C. 20305

2 U.S. Weather Bureau, c/o U.S. Atomic Energy Commission, P.O. Box 1676, ATTN: Robert W. Titus, Las Vegas, Nevada

2 Eberline Instrument Corporation, 805 Early Street, ATTN: William S. Johnson, Sr., Santa Fe, New Mexico

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