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Project 4.2

Effects of Very-Low-Yield Bursts on Biological Specimens (Swine and Mice)

April-October 1958

Headquarters Field Command
Defense Atomic Support Agency
Sandia Base, Albuquerque, New Mexico

September 15, 1961

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Extract version prepared for:

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FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is all currently classified as Restricted Data or Formerly Restricted Data under the provision of the Atomic Energy Act of 1954, (as amended) or is National Security Information.

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ABSTRACT

During Shots Hamilton and Humboldt, swine placed in a tactical environment were used as a biological target, with immediate lethality as the principal objective. The animals were exposed in three different types of foxholes, M-46 tanks, and M-59 armored personnel carriers at distances where lethal levels of radiation might be expected without complete destruction of the environment. Also included in the experiment was an exposure array designed to extend the data obtained during Operation Plumbbob for median lethal dose in 30 days (LD_{50-30}) for swine and also to determine the relative biological effectiveness (RBE), with death as an end point, of neutrons versus gamma. The LD_{50-30} study in swine was supported by a parallel mouse-exposure program to exploit past experience with mice.

Another experiment was designed to evaluate chemical pre-protection with aminoethyl-isothiuronium (AET) against radiation fluxes. In addition, a technique of neutron dosimetry — Na^{24} induced activity in blood — was used in the field.

Because Shot Hamilton failed to give a yield in the range expected, the biological objectives were not attained.

For Shot Humboldt, immediate lethality was the only objective. Immediate lethality occurred only at ranges where the environment was destroyed by blast; precise cause of death in the exposed swine could not be determined.

Swine protected from blast and thermal in M-59 armored personnel carriers at 27-yard slant range from Shot Humboldt received doses in excess of 50,000 rads, gamma plus neutrons, and survived in excess of 2 hours. Four swine were recovered alive from the two-thirds-covered foxholes at slant ranges of 20, 21, 22, and 26 yards, having received in excess of 9,000 rads, gamma plus neutrons. Doses in all two-thirds-covered foxholes were much less than 40,000 rads, and early death of the swine was primarily due to blast and suffocation. In a normal tactical environment, it is probably not possible to achieve doses above 50,000 rads without introducing serious complicating factors due to direct blast or trench collapse.

It appears that measurement of neutron-induced Na^{24} activity in the blood is a feasible method for estimating the neutron dose received.

FOREWORD

This report presents the final results of one of the projects participating in the military-effect programs of Operation Hardtack. Overall information about this and the other military-effect projects can be obtained from ITR-1660, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussions of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.

PREFACE

The Biomedical Task Force Detachment, Project 4.2, was organized at the direction of The Surgeon General, U.S. Army, Major General S. B. Hayes, MC. The executive agency was directed to be the Walter Reed Army Institute of Research, Washington, D. C., Colonel R. P. Mason, Director, MC. Officer personnel were from Walter Reed Army Institute of Research; U. S. Army Medical Research Laboratory, Fort Knox, Kentucky; and the U. S. Army Medical Service School, Fort Sam Houston, Texas. Enlisted personnel were from the 67th Medical Group, Brooke Army Medical Center, Fort Sam Houston, Texas, Major General William E. Shambora, Commanding General. Superb support of the project by each of these elements is noted.

Because of the time frame in which the project was forced to become operational, this could scarcely have been done without the outstanding efforts of Lt Colonel R. J. Veenstra, VC; Captain James E. Anderson, MSC; Captain P. S. Marshall, MSC; M/Sgt H. O. Taylor; M/Sgt John Ponish; and Sgt Stephen E. Teischer.

Without physical measurements, biological response is meaningless. The sincere cooperation of those members of the Army Chemical Corps Radiological Laboratory (E. H. Bouton, D. Rigotti, and J. C. Maloney), Project 2.12, for gamma and neutron dosimetry is acknowledged.

CONTENTS

ABSTRACT -----	5
FOREWORD -----	6
PREFACE-----	6
CHAPTER 1 INTRODUCTION-----	11
1.1 Objectives-----	11
1.2 Background-----	11
1.2.1 Subproject 4.2.1: Immediate Lethality Study-----	11
1.2.2 Subproject 4.2.2: LD ₅₀₋₃₀ and RBE of Weapon Neutrons in Large Animal (Swine) -----	13
1.2.3 Subproject 4.2.3: LD ₅₀₋₃₀ and RBE in Small Animal (Mice) -----	14
1.2.4 Subproject 4.2.4: Radiation Pre-protection with AET-----	14
1.3 Instrumentation -----	15
1.4 Operational Plan -----	15
1.4.1 Shot Hamilton -----	15
1.4.2 Shot Humboldt-----	16
1.5 Scope of Report -----	16
CHAPTER 2 IMMEDIATE LETHALITY FROM NUCLEAR DETONATIONS -----	17
2.1 Introduction-----	17
2.2 Materials and Methods -----	17
2.2.1 Shot Hamilton -----	17
2.2.2 Shot Humboldt-----	18
2.3 Results-----	19
2.3.1 Shot Hamilton -----	19
2.3.2 Shot Humboldt-----	21
2.4 Discussion -----	22
CHAPTER 3 LARGE-ANIMAL (SWINE) RESPONSE TO WEAPON RADIATION --	41
3.1 Introduction-----	41
3.2 Materials and Methods -----	41
3.2.1 RBE Study -----	41
3.2.2 Clinical Studies -----	42
3.2.3 Laboratory Study -----	42
3.3 Results-----	42
CHAPTER 4 SMALL ANIMAL (MICE) RESPONSE TO WEAPON RADIATION ---	48
4.1 Introduction-----	48
4.2 Materials and Methods -----	48
4.3 Results-----	49

4.4 Discussion	49
CHAPTER 5 RADIATION PRE-PROTECTION WITH AET	55
5.1 Introduction	55
5.2 Materials and Methods	55
5.3 Results	55
5.4 Discussion	56
CHAPTER 6 SUMMARY	58
APPENDIX A DOSIMETRY	59
A.1 Background and Theory	59
A.1.1 Gamma Dosimetry	59
A.1.2 Neutron Measurements	59
A.2 Materials and Methods	60
A.2.1 Shot Hamilton	60
A.2.2 Shot Humboldt	60
A.3 Results	61
A.3.1 Shot Hamilton	61
A.3.2 Shot Humboldt	61
A.4 Discussion	61
APPENDIX B NEUTRON-INDUCED Na^{24} ACTIVITY IN SWINE BLOOD	80
APPENDIX C REPORT ON AIR SAMPLING FOR SHOT HAMILTON	83
REFERENCES	88
TABLES	
2.1 Predicted Air Dose Versus Distance, Shot Hamilton	23
2.2 Shot Hamilton Residual Radiation Readings on the North and South Axes on Early Re-entry	23
2.3 Total Dose Incident to Protected Swine, Shot Hamilton	24
2.4 APC Swine, Shot Humboldt	25
2.5 Two-Thirds-Covered Foxhole Swine, Shot Humboldt	25
3.1 Initial Air Doses (Rads), Shot Hamilton	43
3.2 Average Body Weight	44
3.3 White Blood Cell Count, Percent of Pre-Exposure Counts	44
3.4 Mortality in X-Irradiated Swine	45
3.5 White Blood Cell Count, Percent of Pre-Exposure Counts, of X-Irradiated Swine	45
3.6 Average Body Weight (Pounds) of X-Irradiated Swine	45
4.1 Protocol for RBE Mouse Experiment, Shot Hamilton	50
4.2 Exposure Dose in Rads Inside Lead Hemisphere Stations	50
4.3 Exposure Dose in Rads in Aluminum Hemisphere Stations on South Axis	51
4.4 Exposure Dose in Rads in Aluminum Hemisphere Stations on West Axis	51

4.5	72-Hour Percentage Body Weight Change	51
4.6	Hematopoietic Response of Female Mice	52
4.7	Percent Weight Loss, Spleen and Thymus, 72 Hours Postexposure	52
5.1	Air Exposure Dose in Rads at AET-Treated Stations	57
5.2	72-Hour Percentage Body Weight Change	57
A.1	Initial Gamma Radiation, Surface Stations, Shot Hamilton	63
A.2	Initial Gamma Measurements, Surface Stations, Shot Hamilton	63
A.3	Neutron Measurements, Surface Stations, Shot Hamilton	64
A.4	Initial Gamma Measurements, Protected Stations, Shot Hamilton	64
A.5	Initial Gamma Measurements, Protected Stations, Shot Hamilton	65
A.6	Neutron Measurements, Protected Stations, Shot Hamilton	65
A.7	Initial Gamma and Neutron Measurements, Surface Stations, Shot Humboldt	66
A.8	Initial Gamma and Neutron Measurements, Foxholes, and Armored Personnel Carriers, Shot Humboldt	66
A.9	Calculated Theoretical Dose if all Vehicles had been at 50-Yard Distance, Shot Hamilton	67
B.1	Na ²⁴ Dosimetry, Shot Hamilton	81
B.2	Na ²⁴ Dosimetry, Shot Hamilton	82
B.3	Na ²⁴ Dosimetry, Shot Humboldt	82
C.1	Concentration of Airborne Plutonium, Initial Cloud at H + 15 Minutes, Shot Hamilton	84
C.2	Concentration of Airborne Plutonium at 3-r Line at H + 2 Hours, Shot Hamilton	84
C.3	Concentration of Airborne Plutonium, Resuspended and Airborne, Shot Hamilton	85
C.4	Concentration of Airborne Alpha Emitting Material Resuspended, D - 5 and D + 4 Days	85
C.5	Concentration of Airborne Plutonium at Weapon Delivery Distance	85

FIGURES

2.1	M-46 tank and M-59 armored personnel carrier used for animal placement	26
2.2	Open, two-thirds-covered and offset foxholes	27
2.3	Offset foxhole under construction showing tunnel of galvanized conduit	28
2.4	Offset foxhole showing completed tunnel and demonstrating overall depth	29
2.5	Two-thirds-covered foxhole, facing away from ground zero and demonstrating depth	30
2.6	North axis array, Subproject 4.2.1	31
2.7	South axis array, Subproject 4.2.1	31
2.8	Safe-user exposure array	32
2.9	Subproject 4.2.1 exposure array, Shot Hamilton	33
2.10	Card for recording animal condition on early reentry	34
2.11	Exposure array, Shot Humboldt	34
2.12	Aluminum liner in Humboldt open foxhole	35
2.13	Blast damage to APC, Shot Humboldt	35
2.14	Postshot view of animals in APC, Shot Humboldt	36
2.15	Location of swine in APC's, Shot Humboldt	37
2.16	Ground zero, post detonation, Shot Humboldt	37
2.17	Two-thirds-covered foxhole, post detonation, Shot Humboldt	38

2.18	Open foxhole, post detonation, Shot Humboldt -----	38
2.19	Recovery of a live animal from two-thirds-covered foxhole, Shot Humboldt -----	39
2.20	Peak overpressure versus distance, Shot Hamilton -----	40
2.21	Peak overpressure versus distance, Shot Humboldt -----	40
3.1	Large animal (swine) exposure stations, Shot Hamilton -----	46
3.2	Aluminum liners for swine, south axis, Shot Hamilton -----	47
4.1	Small animal (mice) exposure stations, Shot Hamilton -----	53
4.2	Lead hemispheres in foreground and aluminum hemispheres in left background, Shot Hamilton -----	54
A.1	Overall exposure array, Shot Hamilton -----	68
A.2	Dosimetry in two-thirds-covered foxhole, Shot Hamilton -----	69
A.3	Dosimetry in open foxhole, Shot Hamilton -----	69
A.4	Placing dosimetry adjacent to tank driver, Shot Hamilton -----	70
A.5	Dosimetry adjacent to APC driver, Shot Hamilton -----	70
A.6	Free-air dosimetry, gamma only, at safe user distance, Shot Hamilton ---	71
A.7	Free-air dosimetry, gamma only -----	71
A.8	National Bureau of Standards film pack and blast shield -----	72
A.9	National Bureau of Standards film pack blast shield -----	72
A.10	Overall exposure array, Shot Humboldt -----	73
A.11	Dosimetry in open foxhole, Shot Humboldt -----	74
A.12	Dosimetry in two-thirds-covered foxhole, Shot Humboldt -----	74
A.13	Dosimetry in APC, Shot Humboldt -----	75
A.14	Initial gamma measurements (surface) versus slant range, Shot Hamilton -----	76
A.15	Neutron measurements (surface) versus slant range, Shot Hamilton -----	77
A.16	Initial gamma measurements (surface) versus slant range, Shot Humboldt -----	78
A.17	Neutron measurements (surface) versus slant range, Shot Humboldt -----	79
C.1	Downwind alpha sampling stations, Shot Hamilton -----	86
C.2	Route of vehicles with air samplers, Shot Hamilton -----	86
C.3	Portable alpha survey meter readings, Shot Hamilton -----	87

Chapter 1

INTRODUCTION

1.1 OBJECTIVES

The objectives were to evaluate the effects of nuclear radiation on biological specimens from a fractional-kiloton nuclear device. Specifically these were to:

1. Determine the immediate lethal response of swine in an environment protected by normal tactical means (foxholes, tanks, and armored personnel carriers).
2. Obtain a relative biological effectiveness (RBE) for weapon neutrons through determination of the median lethal dose in 30 days (LD_{50-30}) in a biological specimen (swine) from both gamma radiation and neutrons.
3. Provide additional backup information on swine through study of the response of small animals (mice) to both gamma radiation and neutrons.
4. Evaluate additional radiation measurements and safety measures.
5. Evaluate oral aminoethylisothiuronium (AET) as a prophylactic agent against weapon gamma and neutron radiation.

In addition, as a byproduct of the basic project activities, efforts were directed toward: determination of the alpha hazard from fractional-kiloton weapons; evaluation of the DT-60 dosimeters; determination of the neutron-induced activity (Na^{24}) in blood as a measure of neutron dose; and evaluation of damage to field fortifications from fractional-kiloton weapons.

1.2 BACKGROUND

1.2.1 Subproject 4.2.1: Immediate Lethality Study

Because of the great difficulty experienced to date in predicting biological response from physical measurements, it was felt that the weapon system—its antipersonnel effect—should be directly assessed by observing effects on a large biological specimen. Survival studies of swine in field fortifications near ground zero during Operation Plumbbob, while inconclusive, certainly indicated that standard field fortifications offer much greater protection from nuclear-weapon effects, particularly radiation, than previously predicted (Reference 1).

The military's need for an evaluation of immediate incapacitation from these effects is obvious. In addition, it is valuable to be able to predict the time of the soldier's death. Criteria for determination of incapacity in experimental animals must include certain

measurable specific functions representative of useful effort by the animal and which can be recorded and compared both before and after exposure to the effects of a nuclear device. These specific functions should include discrimination and memory.

The time frame in which the project was mounted did not permit the selection of an animal capable of such specific functions. It would require months of pretest training, and probably years to make available sufficient animals for statistical significance. In addition, the extrapolation to man of any results of the evaluation of incapacity in the experimental animal would have to be tempered severely because of the lack of an important variable: motivation.

After full consideration, particularly the questions of the number of experimental animals required, their availability and their ability to survive the temperature extremes of the Nevada Test Site (NTS), the swine was chosen as the experimental animal. Considerable background information existed on the response of swine to whole-body radiation and compound trauma. In the time frame of the project, it was impossible to observe specific functions in the swine indicative of degrees of incapacitation. Therefore, it was felt that death, time of death, and, in most instances, cause of death were the end points of choice for the effects study.

In selecting the immediate lethal response of the biological target as the end point in evaluation of the effectiveness of the system, "immediate" must be defined. For the problem at hand "immediate" was taken to mean within 8 to 10 minutes of detonation of the device.

In describing immediate lethal responses to whole-body radiation, it is necessary to deal with massive doses of radiation. Massive dose—for this expression meaning 10^4 r or more—is referred to as the central nervous system syndrome, even though the histological signs of cell injury are not striking. Massive dose has not been studied extensively in the large animal, though several small animal studies have been carried out (References 2 through 7). References 8 through 10 have reported thorough studies of the hyperacute radiation syndrome and the relation between dose and median survival time of mice. Reference 11, drawing on the above data and other reports (References 9, 12 through 16), has a curve relating survival time of mice to radiation dose over the range of 100 to 100,000 r. Although these references are not in agreement as to the exact doses at which inflections in the survival curve occur, all are in agreement that irradiation of the head is responsible for very short survival times at very high dose—above 12,000 r.

Reference 17 presents data on mice, rats, and monkeys, using dose rates of 1,000 to 6,500 r/min from a $Ba^{140}-La^{140}$ source, which shows a rapid but not abrupt transition to the central nervous system type of death. Reference 18 extended the previous high dose studies and demonstrated rather surprising species differences to massive doses of radiation. Rats, mice, hamsters, and guinea pigs were exposed, but only mice showed a graded survival time at the transition dose (the dose that abruptly results in a central nervous system type of death).

As referred to, small laboratory animals have been extensively studied at high radiation doses, but few results with larger animals. monkeys (Reference 17), dogs (Reference 19), and swine (Reference 20) are reported. Data from large animals having cross sections comparable to man would appear to be much more significant than data from smaller animals. Reference 21 reported data, for swine, that suggested an abrupt survival time transition as in the guinea pig and mouse, rather than the smooth semilog response of rat and hamster; this transition occurred at 24,000 r midway between guinea pig (6,000 r) and the mouse (43,000 r). At doses below 24,000 r, the swine demonstrated a striking recovery within 1 to 3 hours after exposure; survival was reported for as long as 3 days after 46,000 r.

The radiation dose that could cause immediate death in man is not known, though several radiologists have stated that doses in excess of 100,000 r would be required. Reference 18 isolated from the Hiroshima data two cases described as having received an estimated 15-percent body surface area burn in addition to an estimated 9,000 rem. These two patients survived 122 hours and 148 hours with no clinical signs of nervous system involvement. Although Reference 18 indicated that these two isolated cases were of little interest in themselves, they were of some interest because of their fit into the laboratory high-dose curves. Even though Reference 18 indicated that the burns may have had little effect on survival time, this is not consistent with other investigators who have reported a remarkable synergism between burns of less than 15-percent body surface area and minimal or sublethal levels of radiation (References 1, 22, and 23). These investigators have reported that combined injury reduced the irradiated-only survival time by about one-third. If this would hold true for massive doses of radiation as well, it could be extrapolated that the two Hiroshima cases might have lived 184 and 222 hours (7.7 and 9.2 days) if burns had not been present. These survival times are of the same order of magnitude as those of mature chimpanzees reported in Reference 24.

Nuclear radiation accidents have exposed laboratory personnel to various lesser levels of radiation, some lethal. A whole-body radiation exposure of 1,900 r resulted in one man's death in 9 days. There was no evidence of incapacitation until the terminal event, which had its onset on the sixth postexposure day (Reference 25).

To study immediate lethality from radiation alone, the animal must be protected from blast and thermal. In the types of fortification and shelters established for the Project by the U. S. Army Corps of Engineers, an exposure of approximately 25,000 rads, gamma plus neutrons, could be expected to swine within the structures without almost certain destruction of the environment. Even at those dose levels, it is readily apparent that blast, particularly, could not be excluded from the structure.

An additional problem for consideration was the effect on personnel within the delivery system. To evaluate this effect, if any, animal placement as well as physical dosimetry at the anticipated point of delivery of the weapon were envisioned.

1.2.2 Subproject 4.2.2: LD₅₀₋₃₀ and RBE of Weapon Neutrons in Large Animal (Swine). The determination of weapon neutron RBE versus gamma in a large biological specimen (swine) was attempted during Operation Plumbbob. No information was gained because of failure of the experimental device to give a yield within the range for which the experiment was planned. A repeat experiment was programmed for Shot Hamilton, a fractional-kiloton device, for which the neutron RBE assumed more clinical importance than with the multi-kiloton devices.

Specific information on the effects of weapon neutrons on large biological specimens approaching man's physical size is not available. As mentioned, previous attempts to obtain this information in the field were unsuccessful. However, during Operation Plumbbob, assuming an RBE of 1 for neutrons versus gamma, the LD₅₀₋₃₀ for combined gamma and

neutron radiation was 486 r + rep (Reference 1). The lethal-dose range was from zero percent at 250 r + rep to 100 percent at 600 r + rep.

The neutron RBE estimates varied from 0.3 to 1.7 (References 26, 27, 28, and 29). In a single laboratory experiment, 40 dogs were exposed to 9-Mev cyclotron-produced neutrons. Single large doses were compared to 250-kvp X-radiation and resulted in an RBE for fast neutrons of 0.8. Comparative data on signs of illness, survival time, serial blood counts, and gross and microscopic pathology revealed no significant differences for the two types of radiation (Reference 26).

Furthermore, the paucity of biological information on the effects of weapon neutrons limits the interpretation of spectral neutron flux data obtained with fission-foil dosimetry systems. In this experiment, maximum physical dosimetry support was planned so that biological data would be correlated with physical measurements.

1.2.3 Subproject 4.2.3: LD_{50-30} and RBE in Small Animal (Mice). The mouse, because of its size and availability, has been extensively studied both in the laboratory and in the field. The response of the mouse to radiation is well known and is described for various levels of radiation. Thus, the mouse-exposure program, paralleling the swine program, would in effect furnish a comparison for the LD_{50-30} and RBE study in the large animal.

Laboratory studies of mice have indicated the RBE of neutrons versus gamma is about 4 for acute lethality and spleen and thymus weight loss (Reference 27). However, in one field test, mice exposed to the neutron flux from a nuclear detonation had an RBE of 1.7 for spleen and thymus weight loss (Reference 28). In another field test, the RBE for thymic atrophy in mice was possibly as high as 8 (Reference 29). The reasons for these field experimental differences are not known. The neutron spectrum and dose rate from laboratory sources are different from nuclear detonations, and this may be one reason for the variation in RBE.

1.2.4 Subproject 4.2.4: Radiation Pre-protection with AET. Whole-body X-radiation lethality in mice can be reduced by the administration of certain chemical agents just prior to the X-ray exposure. Chemicals containing a free sulfhydryl group are the most effective in providing protection. The mechanism of action is unknown. A current theory is that the sulfhydryl groups combine with free radicals produced by the X-radiation of water and thus prevent or minimize subsequent damage.

Of the chemicals available, AET is one of the most promising (Reference 30). In rodents it has a wider margin between the prophylactic and the toxic dose than any other available compound. AET, as well as many of the other agents, is effective when given by mouth, and the duration of protection is now about 4 to 6 hours (References 31 and 32), while, by parenteral injection (any route other than by mouth and usually taken to mean either intravenously or intramuscularly), X-ray exposure must occur within 30 minutes (Reference 30).

Rodents were required for the study of AET, because large animals will not tolerate equivalent weight doses of AET necessary to protect mice. Swine have a minimum lethal dose of about 75 mg/kg of AET by intraperitoneal injection (injection into the abdominal cavity but not into the intestinal tract). Death occurs within 48 hours (Reference 32). The dose required to protect mice is about 250 mg/kg intraperitoneally. By mouth, the protective dose is about 1,000 mg/kg (References 31 and 32). Such doses in mice will reduce a 100-percent lethal dose of radiation to less than 10-percent mortality in 30 days.

Pre-protection chemical agents have never been tested against the radiation delivered by a nuclear detonation; there are several reasons why this should be done: First, the dose rate in a nuclear detonation far exceeds that of any laboratory source of either gamma or neutron radiation; this may alter the effectiveness of the protecting agent. Second,

there is only a limited amount of study concerning the effectiveness of any of the chemical agents against neutron radiation, either pure or mixed in varying proportions with gamma radiation. There are no published reports of the effectiveness of AET against neutron irradiation. Only cysteine has been tested to date, and it has been found to be of some value, but less than when X or gamma radiation is the source (Reference 33). It is essential that the role of the pre-protection chemical agents be clarified for weapon neutron radiation.

1.3 INSTRUMENTATION

In support of the overall project, an extensive program of physical dosimetry was designed to permit correlation between physical dose and biological result. Both gamma and neutron measurements were planned, utilizing a number of different types of available dosimeters. Because of technical and administrative problems and for reason of clarity, only one laboratory's results are used in this report (Appendix A).

It was envisioned that there would be a considerable problem in the visual determination of the animal's death within the immediate time frame (Section 1.2.1). This was based on predictions of induced activity within the exposure array as well as fission fragment fallout about ground zero. Even in the laboratory, the sophisticated measurement of certain vital signs has proved difficult in the experimental animal because of the need to restrain and otherwise modify the animal for various monitors (References 34, 35, and 36). Experimental animals should be allowed at least 3 weeks, and preferably longer, after any surgery (particularly if they have had a significant amount of anesthesia). It has even been suggested that pentobarbital would shorten survival time after massive doses (Reference 18).

In order to document certain vital signs of animals exposed at short distances from ground zero and the cessation of these vital signs as indicating death of the animal, a method of vital-sign monitoring was carried out. Certain animals were instrumented with microphones placed subcutaneously over the precordium. With these microphones, heart and respiratory sounds were picked up on a transistorized tape recorder. This tape recorder was placed adjacent to the animal in a relatively blast protected environment. In addition to the recording of heart and respiratory sounds, the electrocardiogram was monitored by a uni-polar lead over hard wire to a paper recorder located about 1 mile distant. Both systems of monitoring were to be carried out on the same animals, again to modify as few animals as possible. Fifteen animals were monitored on Shot Hamilton and 10 on Shot Humboldt.

1.4 OPERATIONAL PLAN

The facilities at the NTS established during Operation Plumbbob were reopened to support Project 4.2.

1.4.1 Shot Hamilton. The animals exposed to the nuclear device were on three axes from ground zero (Figure A.1), and the exposure stations were located from 5 to 800 yards from the device.

A paraffin shield, 4 feet by 4 feet by 8 inches, was placed with its center $2\frac{1}{2}$ feet from the device to attenuate the neutron dose along the major (west) axis.

In order to realize the immediate-lethality objective, it became necessary to expose certain qualified personnel to levels of radiation higher than the established policy of the Office of the Test Manager, NTS Operations. Four teams of two men each, who were

qualified monitors, were to enter as close to ground zero as possible as early as H + 5 minutes. These four early-entry teams were to record the clinical condition of the animals in Subproject 4.2.1 within the immediate time frame as referred to above. Permission was requested, and granted, for these 8 people to receive as much as 25 r of whole-body radiation in realizing their objective. Actually, the operational plan conceived of their receiving in the neighborhood of 15 r.

1.4.2 Shot Humboldt. On this contingency shot, Project 4.2 participated only to evaluate the immediate-lethality objective. Swine were exposed in a protected environment on one, by chance the high-neutron flux, axis from ground zero (Figure 2.11). The exposure stations were located from 5 to 25 yards from ground zero.

1.5 SCOPE OF REPORT

This report furnishes final evaluation of the results of the listed objectives based on final, corrected data (Appendix A). Because a considerable amount of the dosimetry data obtained has never been finalized, it is not included in this report. The raw data is on file at the Walter Reed Army Institute of Research, Washington 12, D. C.

Each chapter describes a subproject, and as such lends itself to separate treatment. Summation of the results of these separate, but related, efforts is made in the summary chapter. Those more biologically significant efforts, secondary to the basic objectives of the project, are included as Appendixes. The less extensive, but none-the-less significant efforts, are abstracted and included in the pertinent narrative and tables, with references to the sources.

Final data is such that it can be said that, during Shot Hamilton, the experiment was negated by failure to obtain levels of radiation sufficient to meet the objectives. During Shot Humboldt, significant radiation levels were obtained at some stations, but, at the majority of stations, blast far overshadowed radiation in the protected environment.

Additional efforts of the project, on a noninterference basis, yielded information that is presented to stand on its own merit for interpretation by the reader.

Chapter 2

IMMEDIATE LETHALITY FROM NUCLEAR DETONATIONS

2.1 INTRODUCTION

The objective of Subproject 4.2.1 was to determine whether immediate lethality occurs in swine in standard field fortifications and armored vehicles from exposure to the prompt nuclear effects of a fractional-kiloton device. An additional factor for consideration was the prompt effect, if any, on personnel in the delivery system at the specified safe-user distances. To evaluate this problem, swine were placed in open pens at distances that were calculated to receive 25 r, depending on the yield of the device.

2.2 MATERIALS AND METHODS

2.2.1 Shot Hamilton. Three types of foxholes and two types of armored vehicles were selected as suitable tactical field fortifications for evaluation of animal lethality. Five M-46 tanks and two M-59 armored personnel carriers (APC's) were used (Figure 2.1). The foxholes—open, two-thirds covered, and offset, as defined in FMS-15—were constructed under supervision of the U. S. Army Engineer Research and Development Laboratory (ERDL) (Figures 2.2 through 2.7). Sixty-four such fortifications consisting of 12 offset foxholes, 26 open foxholes, and 26 two-thirds-closed foxholes were installed. These foxholes and the seven vehicles constituted 71 animal placement stations. Twenty additional animals were placed at distant stations to represent the position of a soldier firing the weapon in a tactical situation (Figure 2.8).

The close stations were situated on the north and south (high neutron flux) axis from ground zero. Table 2.1 lists the calculated air doses. These doses were calculated for various distances and anticipated yields from 5 to 25 tons from the following formula (Reference 1):

$$R = \frac{R_0 W e^{-D/\lambda}}{D^2}$$

Where: R = total dose, rads

R_0 = intercept value depending on the device design, rads - yd²/kt

W = yield, kt

λ = mean free path, yards

D = distance from point of detonation, yards

Substituting in the formula:

$$\text{For gamma: } R_\gamma = \frac{4 \times 10^6 \times W e^{-D/360}}{D^2}$$

$$\text{For high neutron axis: } R_{hn} = \frac{1 \times 10^7 \times W e^{-D/240}}{D^2}$$

$$\text{For low neutron axis: } R_{ln} = \frac{4 \times 10^6 \times W e^{-D/240}}{D^2}$$

After predicting free-air dose, the following transmission factors were used:

Interior Dose/Exterior Dose		
Transmission Factors	Neutron	Gamma
Foxholes, open, 2-man (Reference 37)	0.17	0.07
Foxholes, two-thirds-closed, 1-foot earth coverage (Reference 37)	0.10	0.04
Foxholes, closed, offset (pig in offset) (Reference 37)	0.02	0.003
Tank, medium, M-46 (Reference 38)	0.05	0.15
Armored personnel carrier, M-59 (Reference 38)	0.8	0.6

In the absence of an assured yield for the shot, stations of comparable type were staggered from ground zero to have sufficient spread of station locations to cover either a high or low yield. Figure 2.9 demonstrates the stations for Subproject 4.2.1 and their locations with regard to ground zero. The five safe-distance stations and their relative locations are also shown.

Each station was instrumented for air gamma within the station, and selected stations were instrumented for air neutron fluxes. In addition, the stations were oriented about a free-air, gamma-neutron dosimeter line. All but seven of the animals in environmental array had midline gamma chemical dosimeters, and 10 animals had partial fission foil systems inserted to measure the midline tissue dose of a portion of the neutron spectrum. (Details of physical dosimetry are reported in Appendix A.) In addition to the 71 close stations, the five safe distance stations were instrumented for air gamma. The stations in the exposure array were oriented so that blast and thermal effects could be observed as well as nuclear radiation effects. The 26 open foxholes were covered with a poncho prior to departure of the placement team, to simulate more closely a tactical environment. All animals were in position by H - 4 hours.

Because it was predicted that residual radioactivity about the closer-in stations would prohibit early evaluation of the animals and probably compromise the immediate-lethality objective, certain animals were equipped with vital-sign monitoring devices. Pulse rate, respiratory sounds, and electrocardiograms were recorded.

At H + 3 minutes, two (north and south) early reentry teams departed for ground zero to make initial animal observations, monitoring their entry to ground zero. These personnel recorded the clinical condition of the animals in the 4.2.1 array (Figure 2.10). Animal and dosimetry recovery was accomplished beginning when radiac survey demonstrated that the majority of animals in the exposure array were outside the 3-r/hr isodose line. Photographic documentation of significant findings was made by the recovery group.

2.2.2 Shot Humboldt. Shot Humboldt was a contingency shot in which Project 4.2 participated. The location for this shot was not finalized until late afternoon of D - 2 days.

Because of the time frame in which to put an operational program into effect, only the immediate-lethality subproject was programed.

On one azimuth from ground zero, two types of foxholes—open and two-thirds covered, similar to those of Shot Hamilton—were arranged extending out from 5 yards from ground zero (Figure 2.11).

Disposition of the stations was not on a basis of calculated dose versus yield of the device, but the stations were placed as close to ground zero as operationally feasible. Factors limiting the number of stations were: time to plan the event, numbers of animals available for the event, the sector available, and the nature of the soil about ground zero. This latter factor needs emphasis. Area 3, Yucca Flat, was finally selected as the site for Shot Humboldt. Here the soil was very loose, and foxholes of the type used for Shot Hamilton were very susceptible to collapse. The sides of any entrenchment in such soil would spontaneously chip away, and to prevent injury to the animal in such an environment prior to the detonation of the device, an aluminum liner was placed in the foxhole (Figure 2.12). This further compounded the artificiality of the exposure array. Past field experience had shown that the liners would not contribute to any attenuation of incident radiation to the animal (References 1 and 28). Twenty-five open and two-thirds covered foxholes were established.

Preliminary data from Shot Hamilton led to the conclusion that, if the predicted yield of the device were achieved, immediate observation of the animals in the exposure array would not be possible within authorized radiation levels. Qualified personnel for observing the animals had already received significant personnel radiation exposure. With an unpredictable yield again anticipated, it was not felt that repeat exposure of these people was justified. Therefore, in order to evaluate the animals early, two M-59 APC's were positioned end-on, with their midpoint at a slant range of 30 yards from the device. Each contained 20 animals. The animals were tethered in such a fashion as to distribute them the length of the carrier. To these vehicles were attached 3,000-foot steel cables, permitting recovery to the 100-mr/hr line. The APC's were recovered immediately after the detonation. Evaluation of the animals in the foxholes was to be carried out when radiation survey personnel reported that the area was reading no more than 3 r/hr.

Sixty-five swine were exposed on Shot Humboldt. All animals were in position by $H - 4\frac{1}{2}$ hours.

Each line of foxholes had the station on either side of the axis through the center of the array instrumented for air gamma and neutrons within the foxhole. In addition there was a free-air, gamma-neutron dosimeter line along the central axis. The APC's had outside gamma dosimetry and inside gamma and neutron dosimetry (Figure A.13). There were five animals in each APC with midline gamma chemical dosimeters; these animals had been salvaged from Shot Hamilton. As on Shot Hamilton, it was predicted that radioactivity at the closer-in stations, where immediate lethality was more probable, would prohibit early evaluation of the animals. Accordingly, the animals on the two closest-in lines, 10 in number, were equipped with vital-sign monitoring devices. Pulse rate, respiratory sounds, and electrocardiogram were recorded.

It was planned to evaluate those animals in the APC's within 15 minutes of their exposure. Those animals in the foxholes would not be observed until radioactivity decay permitted entry.

2.3 RESULTS

2.3.1 Shot Hamilton. The Hamilton device was detonated in Frenchman Flat with a resulting yield (1.17 tons) outside that range of yields for which the experimental plan was

designed (15 ± 10 tons). There was no immediate lethality recorded by the early entry teams, and there was no demonstrable injury to any of the animals from blast or thermal. The early entry teams recorded radioactivity on their entry to ground zero (Table 2.2). The south entry team encountered the edge of the radioactive cloud as it drifted from ground zero. This accounts for the unusual levels of activity encountered and seeming discrepancies in the readings. As the south team neared ground zero, they emerged from this cloud, and their readings approached those of the north team. None of the armored vehicles were disturbed by the detonation.

All animals in the exposure array were accounted for. Two animals were recovered, dead, on D + 3 days. These animals were buried by earth spalling from the sides of the foxholes. Post-mortem examination demonstrated that they had died of suffocation. Some of the animals in the closer two-thirds-covered and open foxholes were partially buried by earth that chipped away from the sides of the foxholes, but the animals appeared unhurt. In several of the open foxholes, the animals were observed to be completely buried by earth that filled the holes with up to 2 feet of loose dirt. In spite of this, these animals were alive. There was considerable wooden debris scattered about, and heat from the burning debris was an additional limiting factor in early evaluation.

Listed in Table 2.3 are station, distance from ground zero, and dose (gamma and neutrons in rads) measured inside the station. Some of the animals in the close-in stations eventually succumbed to their radiation, and their day of death is noted.

Residual radiation—whether induced activity or fission-fragment fallout—did not compromise the early reentry and evaluation of the animals because of the extremely low yield obtained. Ninety percent of the animals were observed and their clinical status documented by H + 22 minutes. All animals observed were alive and active. Animals recovered from the array were followed clinically for 15 days after Shot Hamilton, except for the 10 animals with midline partial neutron foil systems, which were immediately sacrificed for recovery of their dosimeters.

In the case of the vital sign monitoring, unsatisfactory records were obtained on those animals both as regards the heart beat and respiratory sounds and the electrocardiogram. In most instances, the failure was due to inability to control the animal after placement, with the subsequent result that the monitoring leads became disconnected prior to the detonation of the device. In other instances, undecipherable records prohibited definite analysis and conclusions. In the first few days after Shot Hamilton, the majority of the monitored animals developed such untoward reactions to their wiring and microphones that they were sacrificed.

Those animals that succumbed during the followup period did so in a fashion and at a time after the detonation consistent with the well-documented response of swine to levels of radiation (Reference 1).

None of the animals at the safe-user distances suffered from any of the effects of the detonation.

The most distant foxholes without cover (55 yards from ground zero) suffered no apparent damage. Such foxholes at ranges closer to ground zero suffered spalling of the sides in severity increasing with decreasing range. In essentially every case, the top 1 to $1\frac{1}{2}$ feet of the foxholes was undamaged, with the spalling occurring below this level. The amount of spalled material ranged from essentially none to as much as 20 inches on the base of the foxhole.

The cover of the two-thirds-covered foxholes consisted of one layer of 6- by 6-inch timbers, not connected to each other, overlaid by sandbags and a shallow layer of loose soil. In no case were the timbers broken. At close ranges, both the foxholes with the opening facing toward ground zero and those facing away from ground zero had the timbers

loosened and separated, allowing sifting of material into the foxholes. Spalling of material from the sides of the holes occurred as in the uncovered holes. Closer holes were filled with up to 2½ feet of spalled and sifted material.

Results in foxholes with offsets compared in all major respects to those that were two-thirds covered.

2.3.2 Shot Humboldt. The Humboldt device gave a yield of 7.8 tons, a yield less than that predicted. The APC's were recovered promptly. One vehicle was opened and the animal evacuation started by H + 12 minutes, the other by H + 14 minutes. Induced activity in the vehicles at initial observation gave readings of 100 r/hr at 3 feet away from the rear of the vehicle, and this delayed animal recovery. Radiation readings after 1 hour had decayed to 35 r/hr. The tops of both the APC's were dished in (Figure 2.13), and much of the inside equipment was torn loose (Figure 2.14), indicating that the vehicle had been subjected to considerable blast pressure.

All animals in both APC's were alive on recovery. The animal in the driver's position of the south APC could not be recovered, because it had been wedged in by a portion of buckled armor plate. This animal was alive on initial observation but was dead at H + 10 hours, when another attempt was made to extricate it.

The majority of the animals initially exhibited ataxia and considerable apathy to any stimulus. There were scattered vomiting and diarrhea among those recovered. A few animals, ultimately the first to die, demonstrated tetanic rigor, abnormal respiratory efforts, and complete loss of response to any stimulus. The swine from the APC's are listed in Table 2.4. Even though the swine were tethered in position, it was not practicable to assign each animal to a finite distance from the device, because field dosimetry is not this sophisticated nor is biological response this consistent. Accordingly, the animals have been arbitrarily divided into three groups—forward, middle, and aft (Figure 2.15)—and the radiation dose to each group presented as incident dose to the APC. Survival time of each animal is listed.

Entry to the foxhole array was not possible until H + 10 hours, and even at this time the better part of the array was within a 40-r/hr isodose line. Observation at this time demonstrated almost total destruction of the foxholes by blast (Figures 2.16 through 2.18). There was no evidence of thermal effects about the foxholes. The foxholes were almost completely obliterated by loose fill up to 3 feet in depth. The aluminum liners, where visible, were completely collapsed and in some cases split open by the blast. In spite of this destruction, four animals were recovered (Figure 2.19) from the foxhole array. All were from two-thirds-covered foxholes in the most-distant-two lines of the array. Radiation dosage data is available for only one of these animals, but this station, Station 18, was the nearest to the device. Using this position as a reference point, all recovered animals are tabulated, with survival time, in Table 2.5. At autopsy, these animals all evidenced extensive pathology from secondary blast, particularly in the lungs.

Complete dosimetry results of Shot Humboldt are tabulated in Tables A.7 and A.8.

Results of the vital sign monitoring were negative. The hard-wire recording of the electrocardiogram was distorted in all instances by the interference from a radio signal of unknown origin. All that can be said is that the animals were alive in most instances at the time of the detonation, but subsequent to the detonation, recordings were impossible to decipher. The transistorized tape recordings of heart sounds and respiratory sounds were not recovered because of the destruction of the environment by the blast overpressures.

2.4 DISCUSSION

The radiation levels produced by Shot Hamilton were not sufficient to produce immediate symptoms in any of the swine exposed.

For Shot Humboldt, it can be said that the majority of the animals recovered from the APC's manifested symptoms of one sort or another within 15 minutes of their exposure; however, none of the animals were immediate fatalities. It does appear, however, that in the free-air dose ranges achieved (63,000 to 88,000 rads, gamma plus neutrons) death between 2 and 24 hours is probable. The radiation syndrome recorded in the swine from the APC's is consistent with that previously noted in both rodents and subhuman primates radiated with similar doses (Reference 39). It is interesting that, as a group, the larger swine demonstrated fewer symptoms, and their onset of recovery from apathy and ataxia was sooner. This did not contribute to longer survival, however.

Those animals recovered alive from the foxholes of the Humboldt array evidenced no symptoms for 24 hours. On recovery, the animals were alert and active but demonstrated no inclination to eat. Apathy, then vomiting, followed by ataxia and clonic convulsions—the typical syndrome previously recorded—was the terminal course of these animals.

The blast pressures recorded from Shots Hamilton and Humboldt are presented in Figures 2.20 and 2.21. On Shot Humboldt, the APC's received approximately 90 psi peak overpressure. The foxholes, being closer, were subjected to greater pressures, those inside 21-yard slant range experiencing pressures in excess of 200 psi. In the foxholes, the obvious immediate lethal factor was blast. What contribution the high radiation dose made was indeterminate. The contribution of the aluminum liners to the blast effect in the way of secondary missiles is unknown, but among the four animals recovered alive, severe lacerations through the superficial muscle layers were in evidence.

TABLE 2.1 PREDICTED AIR DOSE VERSUS DISTANCE, SHOT HAMILTON

Dose as 10^3 rem, with an RBE (lethality) for neutrons of 1.3.

Ground Distance	Offset		2/3 Closed		Open		M-46 Tank		M-59 APC	
	5 Tons	25 Tons	5 Tons	25 Tons	5 Tons	25 Tons	5 Tons	25 Tons	5 Tons	25 Tons
yards										
5	4.4	22.2								
7.5	3.7	18.6								
10	3.3	17.3								
12.5	2.8	14.1	15.2	75.8						
15	2.4	12.1	13.0	65.0	22.2	111.1				
17.5	1.8	8.9	11.0	54.8	18.7	93.7				
20			9.6	48.0	16.3	81.6				
22.5			8.2	41.1	14.0	70.1				
25			7.3	36.7	12.5	62.6				
27.5			6.2	31.0	10.6	52.9				
30			5.4	27.1	9.2	46.2				
32.5					8.1	40.6				
35					7.1	35.4	20.2	100.9		
37.5					6.3	31.4				
40			3.2	16.2	5.5	27.7				
45							12.9	64.7		
55					3.0	15.0	8.5	42.6		
60									13.0	64.8
65							6.1	30.3		
70										
80									9.3	46.4

TABLE 2.2 SHOT HAMILTON RESIDUAL RADIATION READINGS ON THE NORTH AND SOUTH AXES ON EARLY RE-ENTRY

Distance From Ground Zero	Time After H Hour	Radiac Reading*	
		North	South
yards	min	r/hr	r/hr
400	9	0.9	0.75
300	9	0.9	150.0
200	9	1.2	200.0
150	9	1.9	200.0
100	10	2.5	200.0
80	10	10.0	—
70	10	—	120.0
60	10	—	125.0
50	10	—	130.0
40	12	—	11.0
30	12	—	130.0
20	12	50.0	140.0
10	15	120.0	150.0
5	22	340.0	—
45 (Tank)	15	—	2.0
32.5 (Tank)	12	4.8 outside hull	—
65.0 (APC)	11	1.8 outside hull	—

* AN/PDR-29

TABLE 2.3 TOTAL DOSE INCIDENT TO PROTECTED SWINE, SHOT HAMILTON

A, armored personnel carrier; □, tank; SU, safe-user pens; Foxholes: O, open; Δ, 2/3-closed; and ◇, offset.

Station Number	Distance Slant Range yards	External Dose Gamma	Died	Station Number	Distance Slant Range yards	External Dose Gamma	Died
1O	57.5	252		41Δ	22.4	957†	D + 8
2O	57.5	244		42Δ	22.4	587†	
3O	43.3	383	D + 9	43Δ	20.7	783†	D + 1
4O	39.0	261	D + 6	44◇	19.3	‡	
5O	34.3	139	D + 5	45◇	17.4	174†	
6O	34.3	240	D + 4	46O	43.3	374	H + 1‡
7Δ	30.0	348†	D + 8	47O	41.0	252	D + 7
8Δ	30.0	400†	D + 8	48O	39.0	286	D + 8
9Δ	30.0	366†	D + 10	49O	36.9	200	H + 1‡
10O	26.0	‡	D + 4	50Δ	34.3	340†	
11◇	26.0	47†		51Δ	31.2	418†	
12Δ	24.0	514†	D + 11	52Δ	31.2	392†	
13Δ	22.4	401†	D + 9	53Δ	31.2	418†	
14O	22.4	~2,000		54O	30.0	400	D + 7
15◇	20.7	‡		55O	30.0	366	D + 5
16◇	18.3	61†		56O	30.0	400	D + 4
17O	41.0	304	D + 10	57Δ	28.0	‡	
18O	36.9	496	D + 1	58O	26.0	914	H + 1‡
19O	31.2	191	D + 4	59Δ	24.0	592†	D + 8
20O	31.2	592	D + 11	60Δ	24.0	505†	D + 4
21O	28.0	‡	D + 6	61◇	22.4	116†	
22O	28.0	618		62O	22.4	~1,568	
23O	28.0	357		63◇	20.7	‡	
24Δ	26.0	461†		64◇	18.3	60	
25Δ	26.0	409†	D + 13	65□	64.0	261	H + 1‡
26O	24.0	1,568		66A	57.5	622	H + 1‡
27◇	22.4	13.9		67□	36.9	374	H + 1‡
28Δ	20.7	783†		68□	37.0	626	H + 1‡
29Δ	20.7	653†		69□	50.5	322	H + 1‡
30◇	19.3	58.4		70□	56.5	435	H + 1‡
31◇	17.4	‡		71A	83.0	340	H + 1‡
32Δ	43.3	200		72SU	600	2.3	
33Δ	43.3	209		73SU	650	1.7	
34Δ	34.3	348†	D + 12	74SU	700	1.3	
35Δ	34.3	392†		75SU	750	196	
36Δ	28.0	470†		76SU	800	0.73	
37Δ	28.0	435†					
38◇	26.0	52.2†					
39Δ	26.0	‡	D + 8				
40O	24.0	1,522	D + 6				

* Project 2.12, from Tables A.4, A.5, and A.6.

† Uncorrected dose. No neutron data.

‡ Recovered too late to yield data.

§ Defective film badge.

¶ Animals sacrificed for internal dosimetry recovery.

TABLE 2.4 APC SWINE, SHOT HUMBOLDT

(70) North APC * Animal Number	Survival Time hrs	Dose, Rads †		Survival Time hrs	(66) South APC * Animal Number
		Gamma	Neutron		
123	3.0	15,680		3.5	229
978	2.5			<10	455
226	10.8			9	884
298	4.2			10.8	916
971	11.2			9	872
922	4.5	13,920		2.5	257
163	10.0			7.2	260
540	21.5			14.8	252
245	11.5			13.5	899
52	> 30			11.0	903
209	15.5	12,190		> 30.0	912
538	8.0			11.2	968
534	9.0			15.2	915
962	13.0			9.8	918
885	9.8			15.8	537
293	8.5			9.2	920
939	11.0			12.0	901
191	3.5			15.2	851
859	16.2			14	9
55	17.8			3.5	902

* See Figure 2.15 for animal location. † From Figures A.16 and A.17.

TABLE 2.5 TWO-THIRDS-COVERED FOXHOLE SWINE, SHOT HUMBOLDT

Animal Number	Station * Number	Slant Range † yards	Dose, 10 ⁵ rads		Survival Time hours
			Free-Air gamma neutrons	Foxhole gamma neutrons	
898	16	22.1			69
405	18	19.91	> 19	5.6	68
311	20	20.7			> 30
391	25	25.5			82

* See Figure 2.11.

† True distance, calculating tower height, distance of station from central axis, and depth of foxhole.

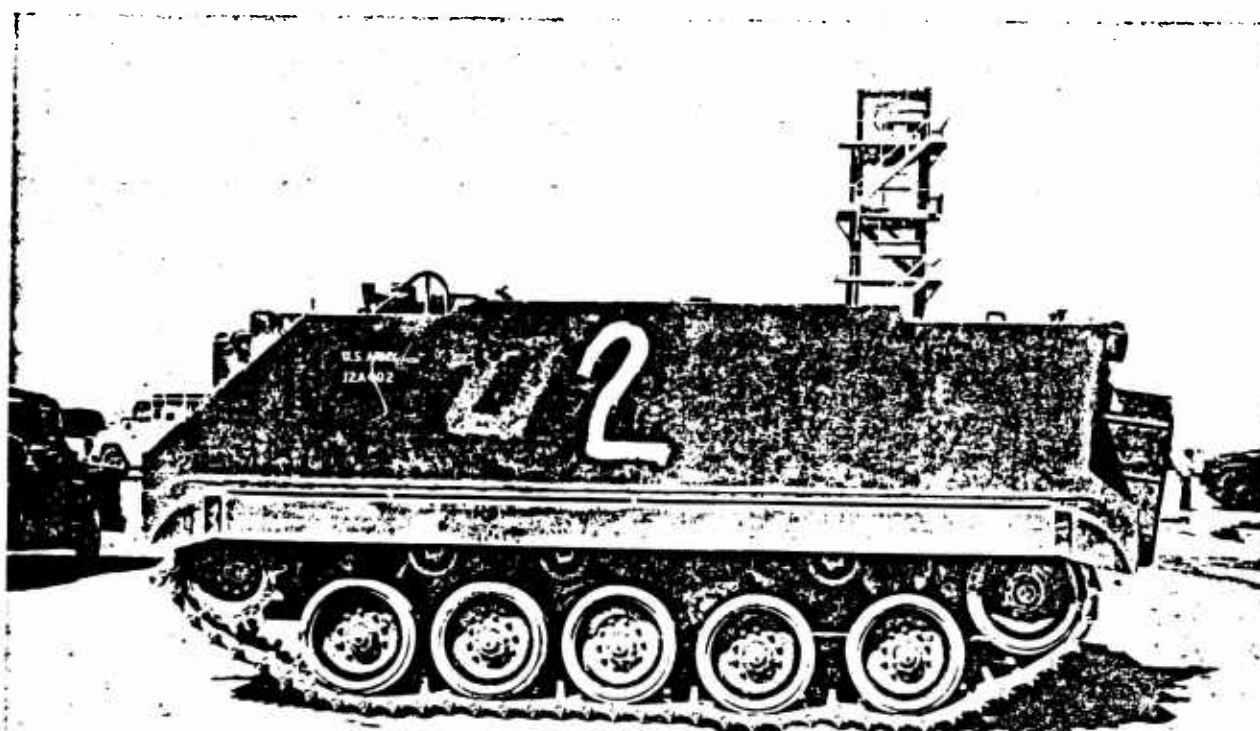
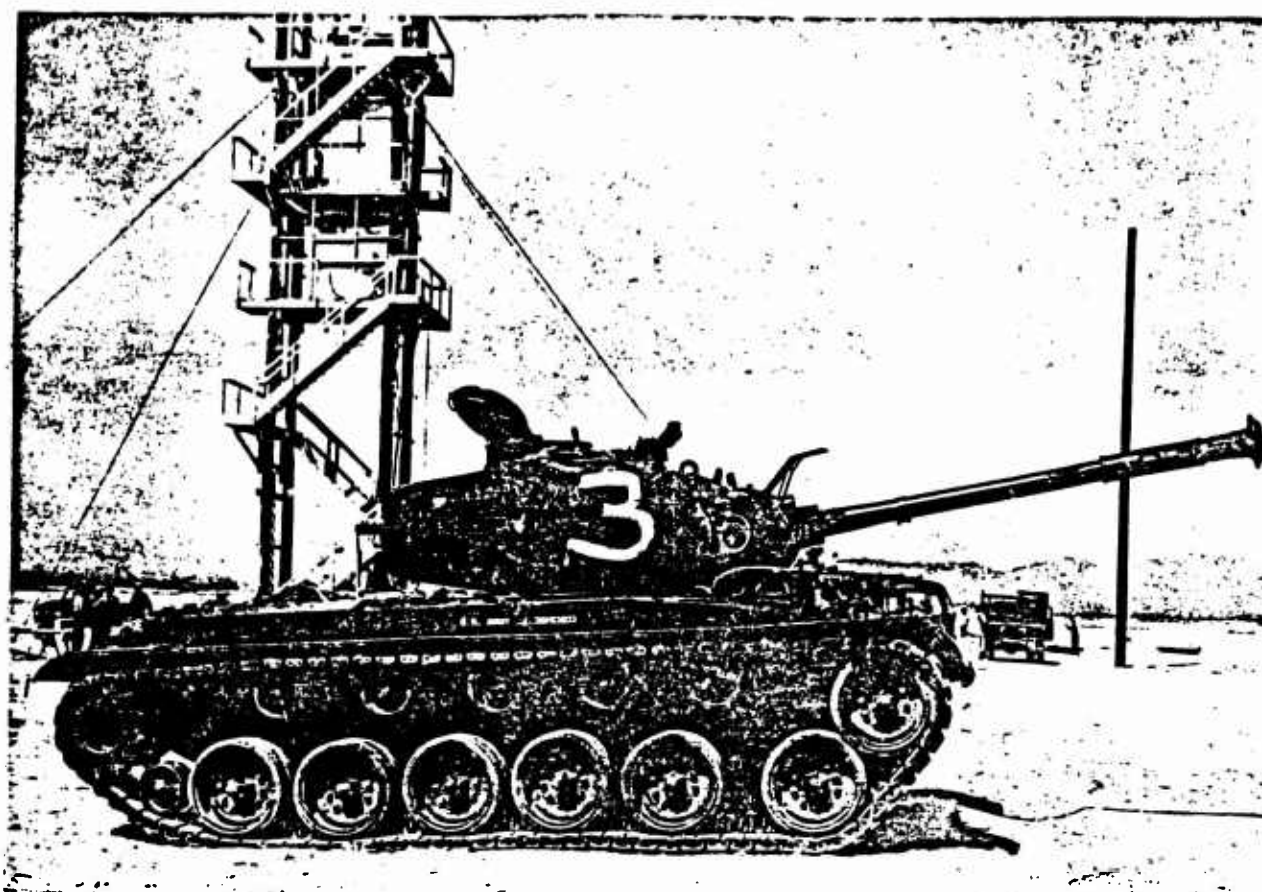
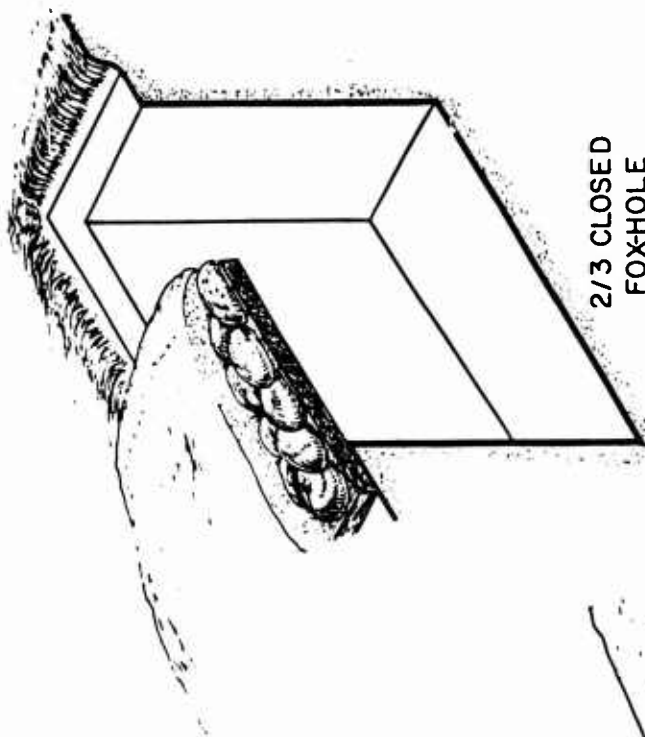
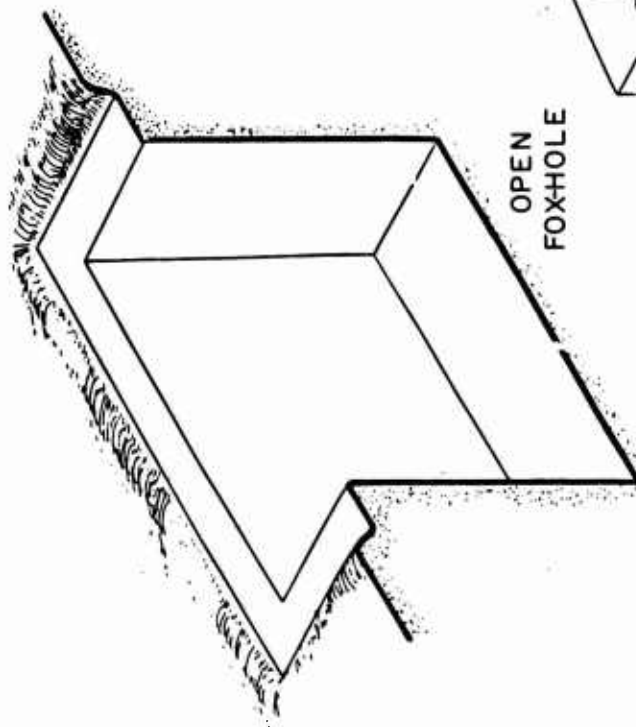


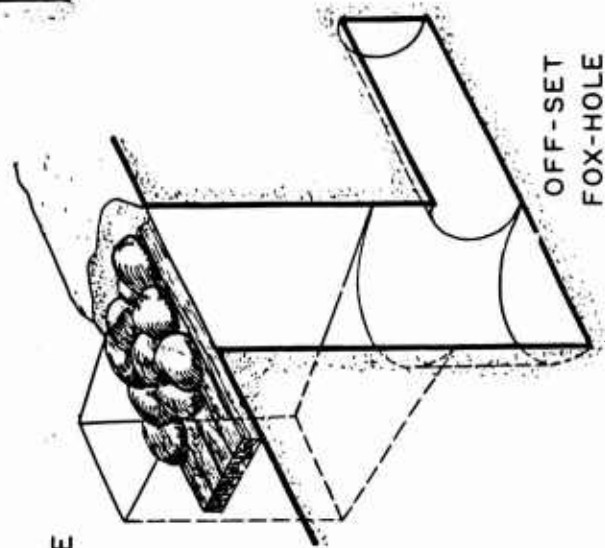
Figure 2.1 M-46 tank and M-59 armored personnel carrier used for animal placement.



2/3 CLOSED
FOX-HOLE



OPEN
FOX-HOLE



OFF-SET
FOX-HOLE

Figure 2.2 Open, two-thirds-covered and offset foxholes.

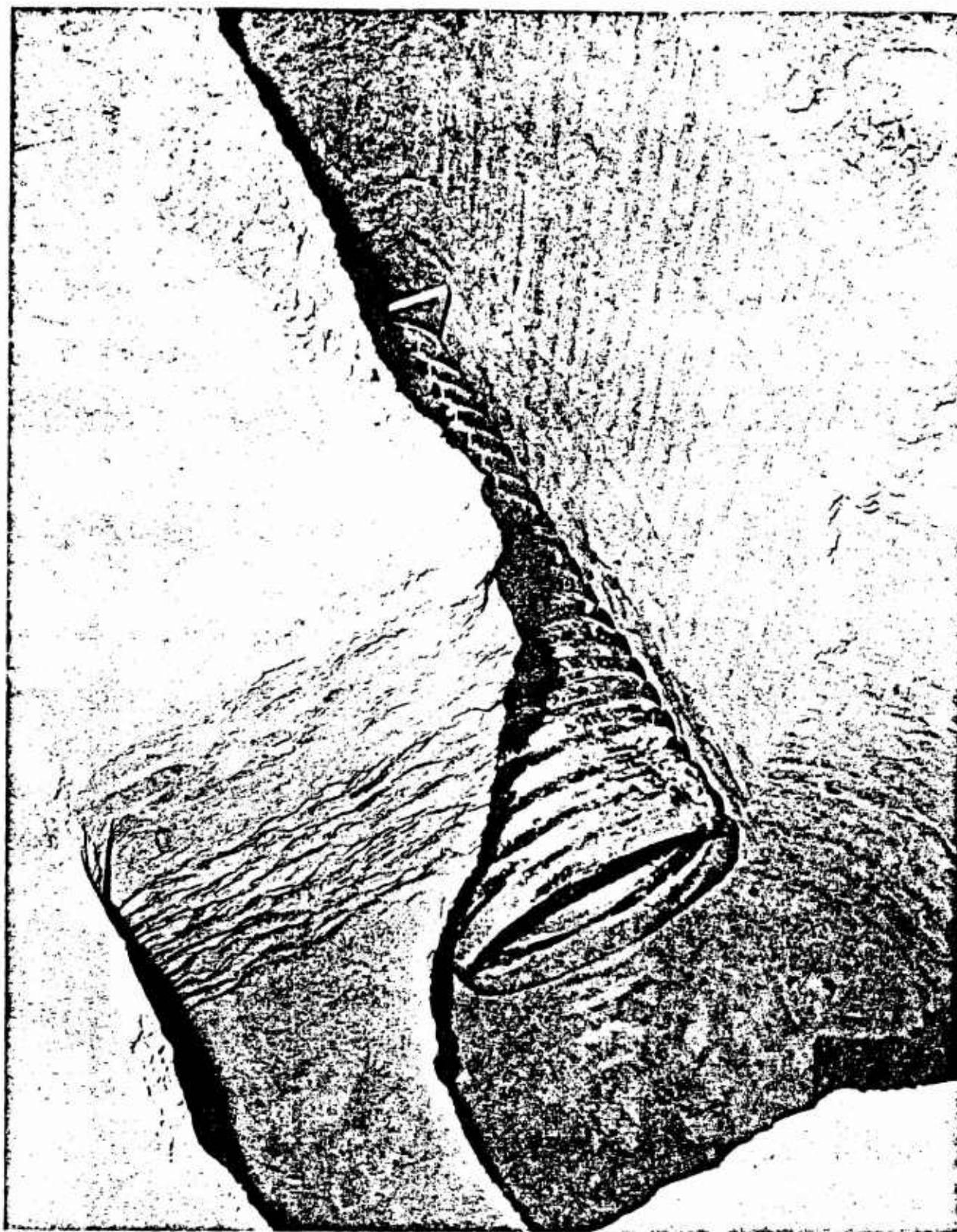


Figure 2.3 Offset foxhole under construction showing tunnel of galvanized conduit.

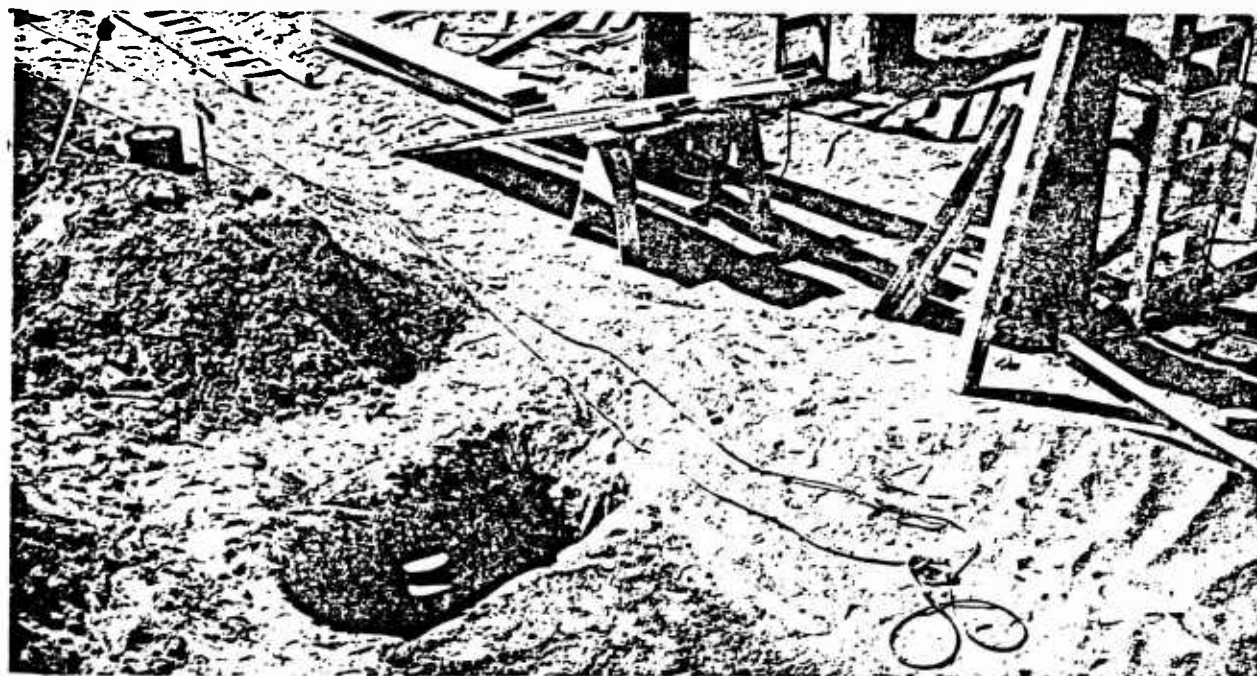


Figure 2.4 Offset foxhole showing completed tunnel (top) and demonstrating overall depth (bottom – man in foxhole).

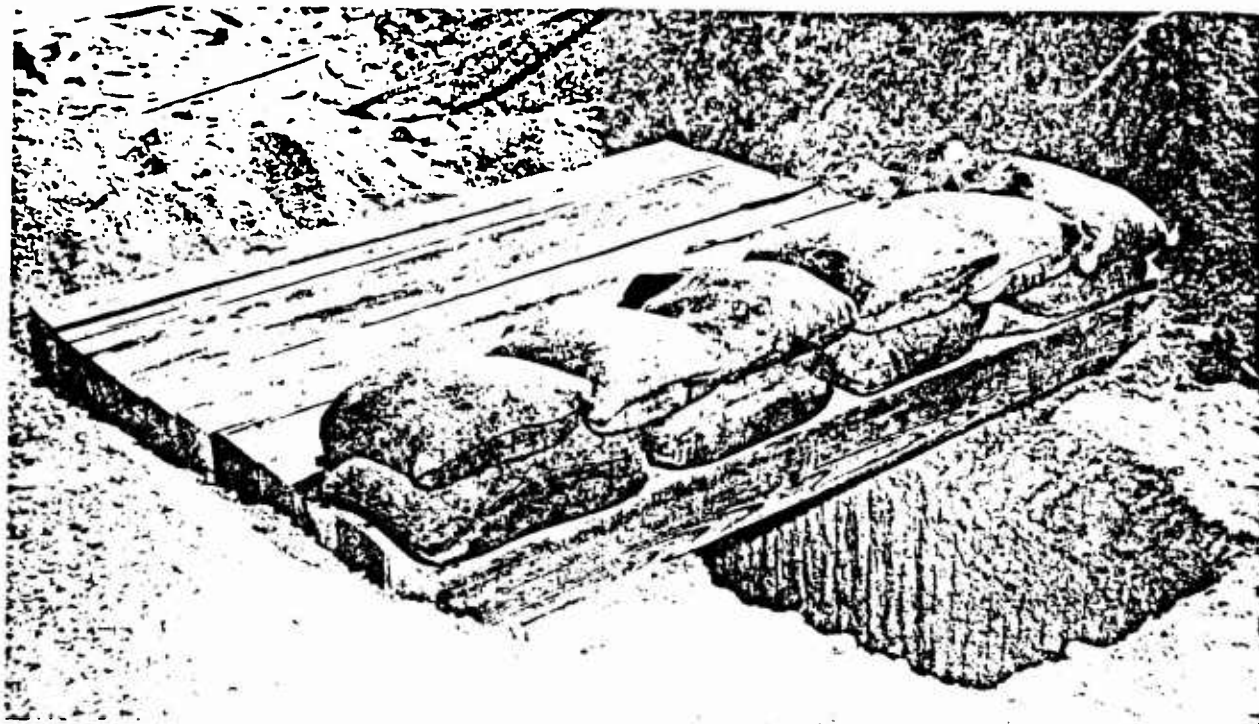


Figure 2.5 Two-thirds-covered foxhole, facing away from ground zero (at top) and demonstrating depth (bottom).



Figure 2.6 North axis array, Subproject 4.2.1.



Figure 2.7 South axis array, Subproject 4.2.1.

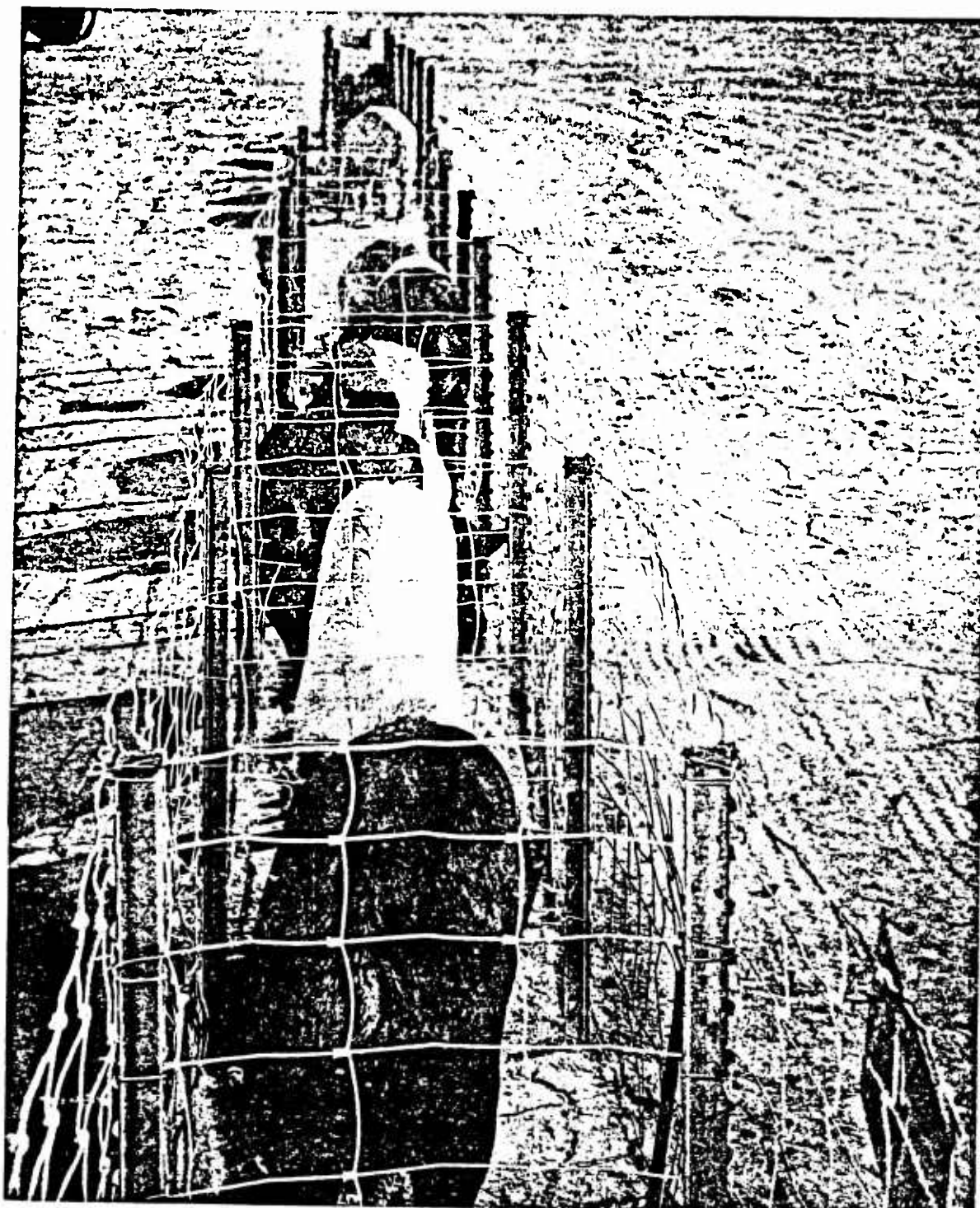


Figure 2.8 Safe-user exposure array.

HAMILTON ARRAY (FF)
4.2.1
15 October, 1958

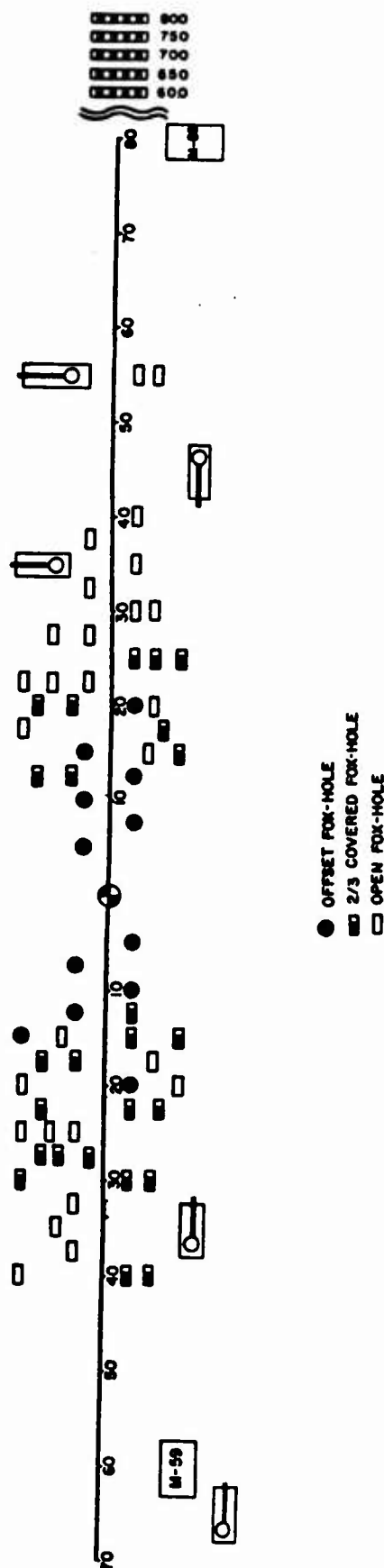


Figure 2.9 Exposure array, Subproject 4.2.1, Shot Hamilton.

CLINICAL EFFECTS EVALUATION CARD - 4.2.1	
FIG NO: 123	STATION NO: 5A TIME: 0812
(Observer will CIRCLE condition of animal)	
DEAD	
LIVING ☒	COMMENTS: Quiet
CONVULSIONS VOMITING UP DOWN ATAXIA	
DATE:	COMMENTS
15 Oct	animal sacrificed for internal dosimetry; animal very vigorous; H+ 45 min.

Figure 2.10 Card for recording animal condition on early reentry.

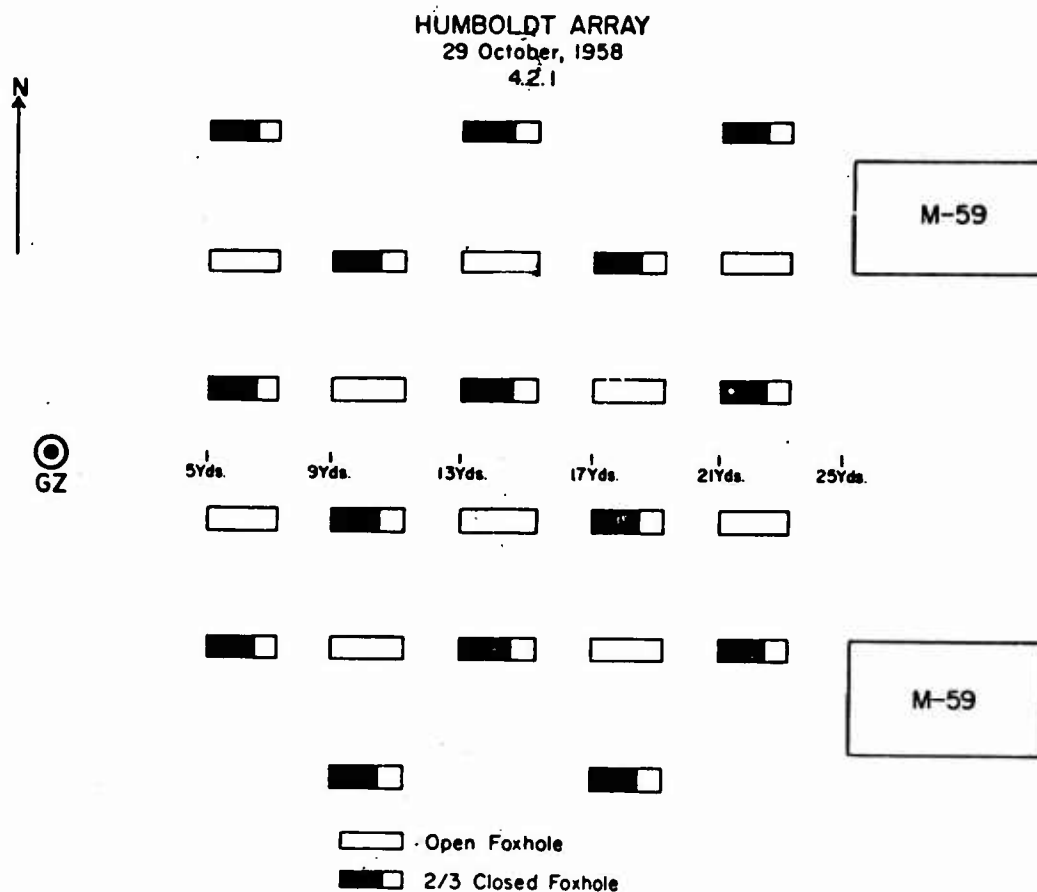


Figure 2.11 Exposure array, Shot Humboldt.

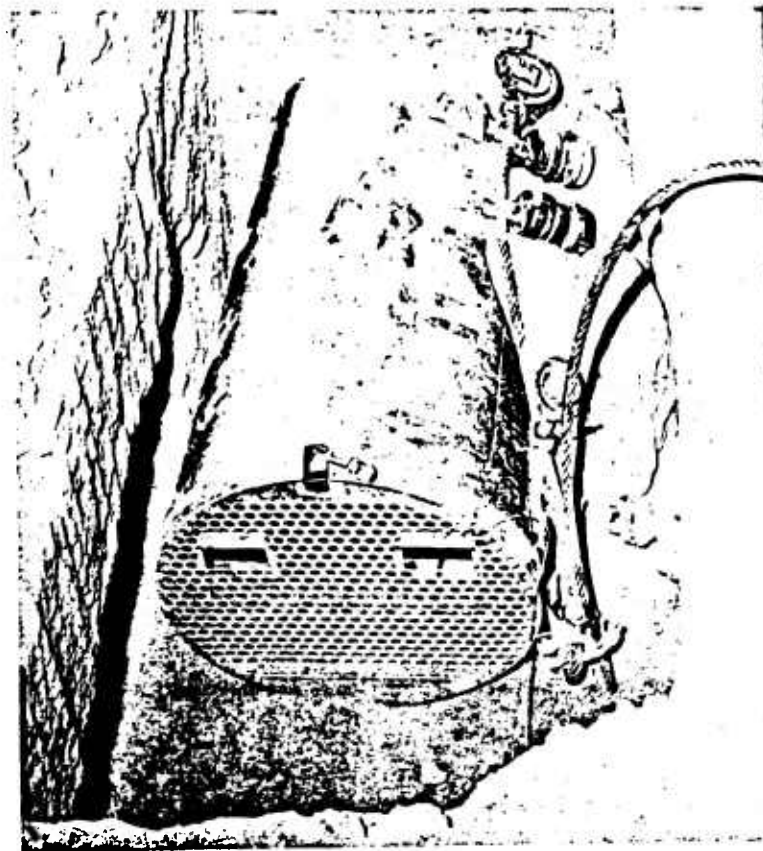


Figure 2.12 Aluminum liner in open foxhole, Shot Humboldt.



Figure 2.13 Blast damage to APC, Shot Humboldt.



Figure 2.14 Postshot view of animals in APC, Shot Humboldt.
Note derangement of vehicle interior by blast.

SOUTH ARMORED PERSONNEL CARRIER			GROUND ZERO ↑ 25 YARDS	NORTH ARMORED PERSONNEL CARRIER		
229		455	28	123		978
884	916	872	FORWARD	226	298	971
257	260	252	30	922	163	540
899	903	912	MIDDLE	245	52	209
968	915	918		538	534	963
537	920	901	32	885	293	939
851	9	902	AFT	191	859	55

Figure 2.15 Location of swine in APC's, Shot Humboldt.
(See Table 2.4.)



Figure 2.16 Ground zero, post detonation, Shot Humboldt.

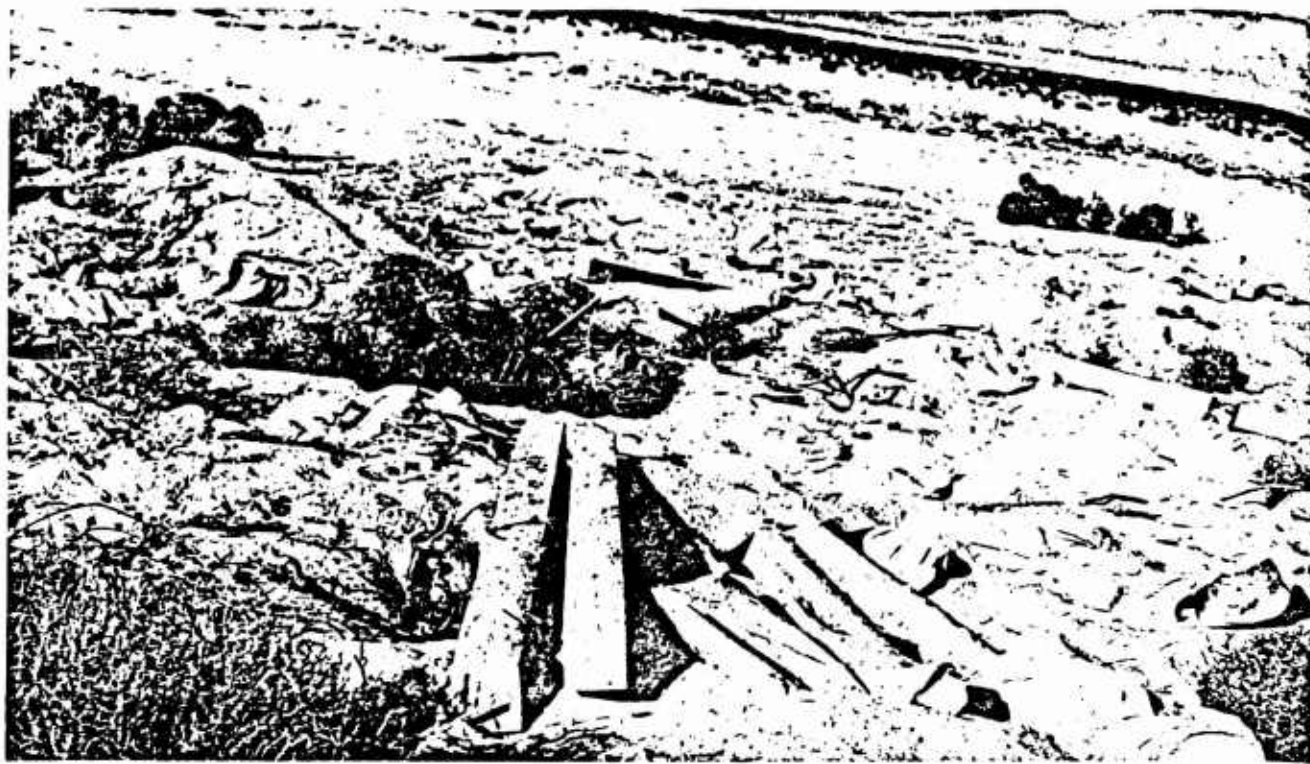


Figure 2.17 Two-thirds-covered foxhole, post detonation, Shot Humboldt. Hole almost completely filled by loose earth.

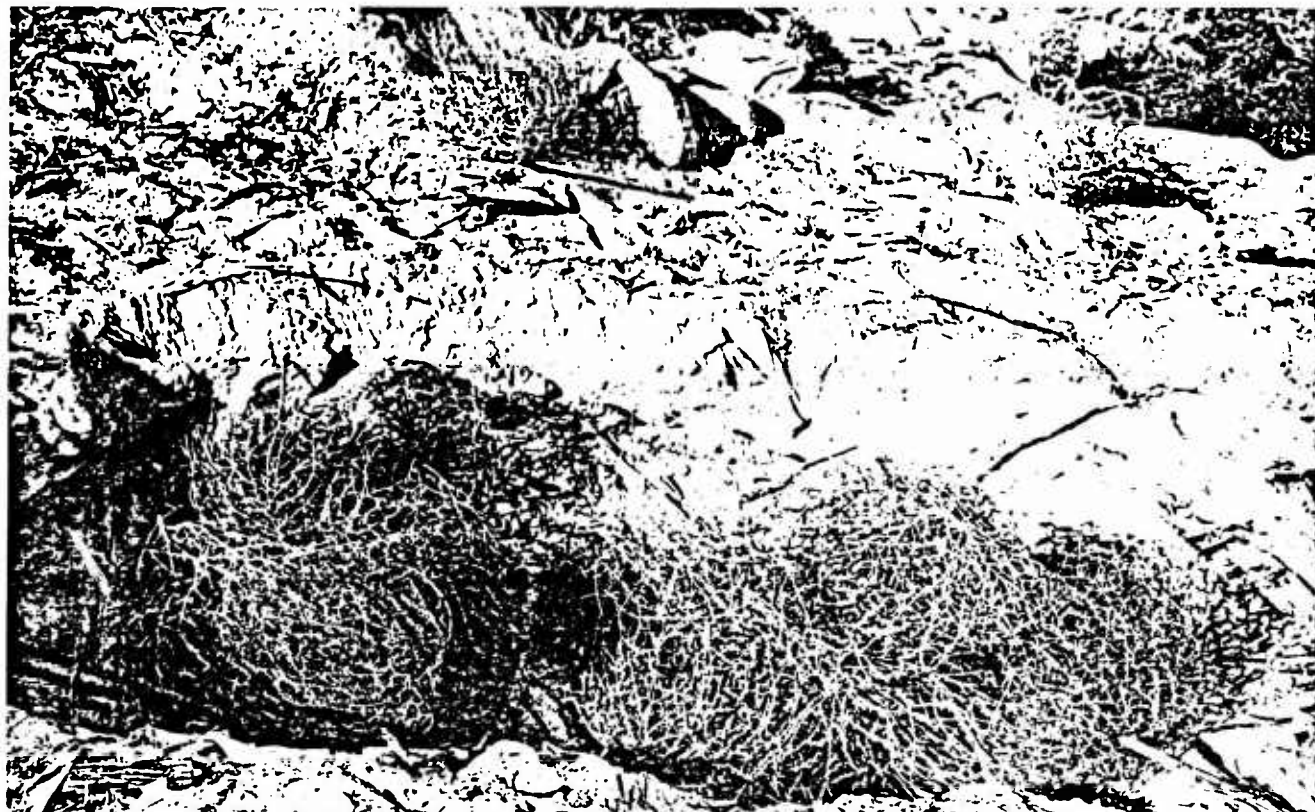


Figure 2.18 Open foxhole, post detonation, Shot Humboldt. Hole almost completely filled with loose earth. No evidence of the aluminum liner.



Figure 2.19 Recovery of a live animal from two-thirds-covered foxhole, Shot Humboldt.

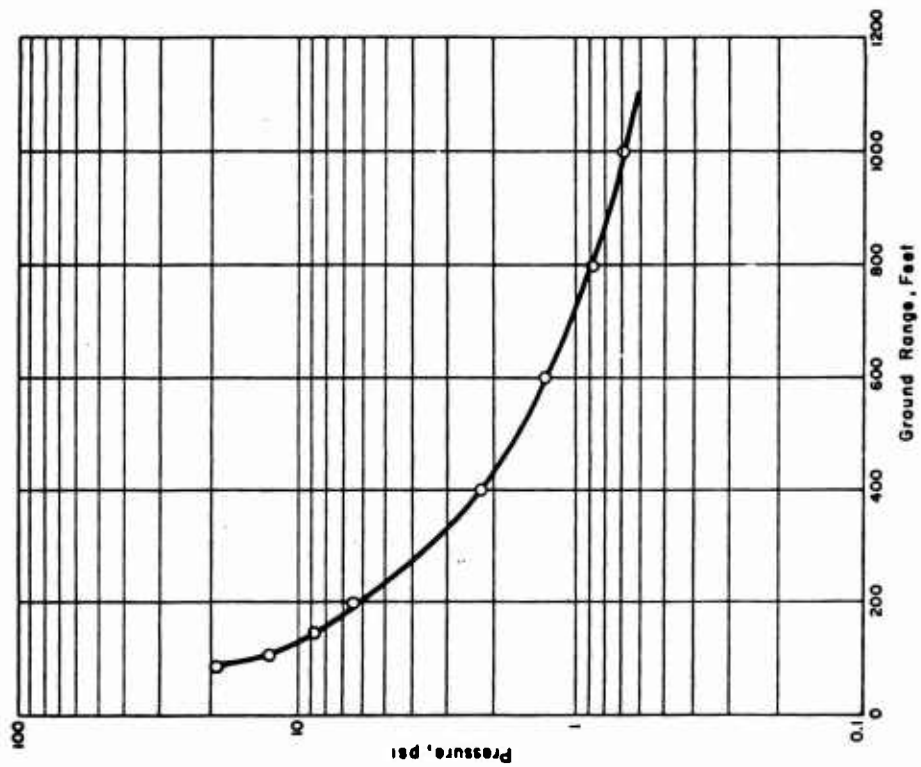


Figure 2.20 Peak overpressure versus distance, Shot Hamilton.

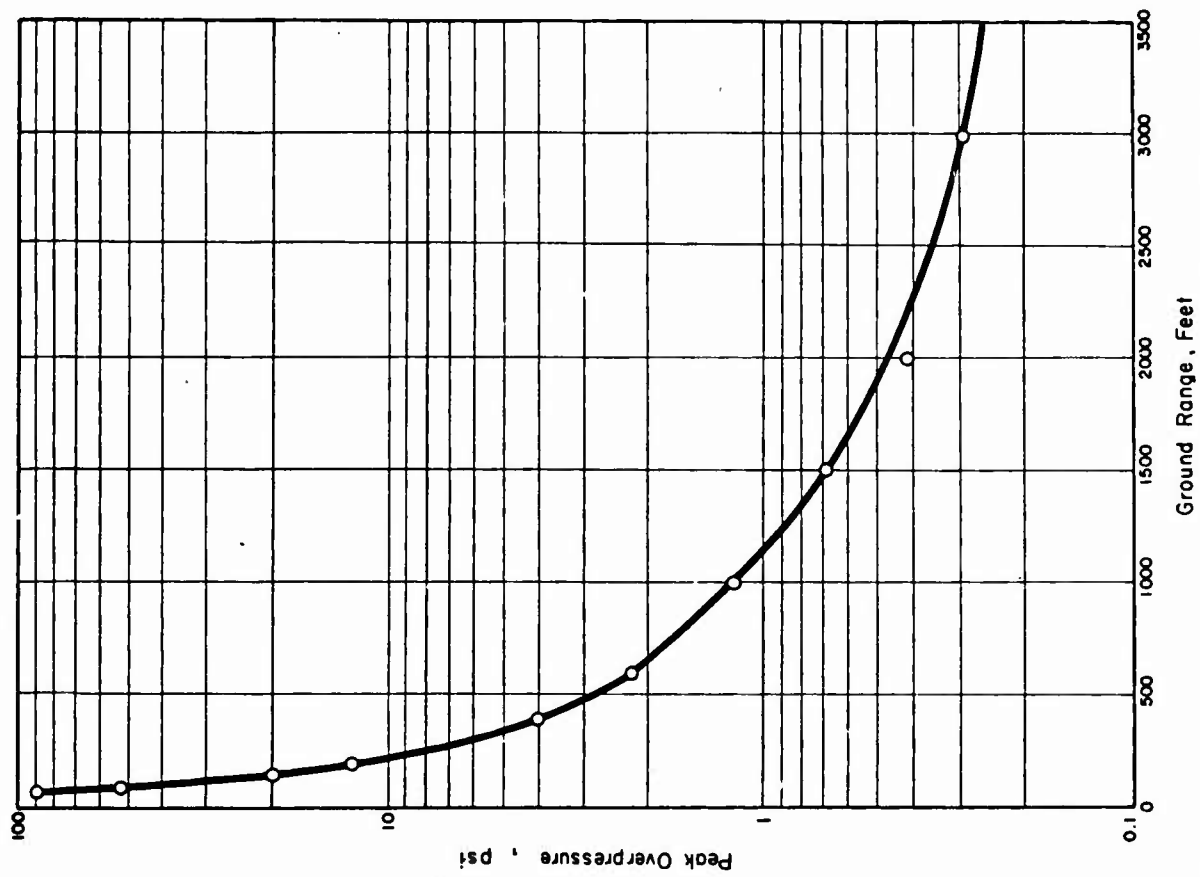


Figure 2.21 Peak overpressure versus distance, Shot Humboldt.

Chapter 3

LARGE-ANIMAL (SWINE) RESPONSE TO WEAPON RADIATION

3.1 INTRODUCTION

Subproject 4.2.2 was designed to obtain a relative biological effectiveness for weapon neutrons through determination of the LD_{50-30} in a biological specimen from both gamma and neutrons. The selected RBE end-point was the median lethal dose in 30 days (LD_{50-30}). Field physical dosimetry for this experiment involved both air dose and midline measurements in the swine. The latter physical measurement proved too inconsistent to correlate with biological response (Appendix A).

3.2 MATERIALS AND METHODS

Using the background data from Operation Plumbbob (Reference 1), Subproject 4.2.2 was designed so that at least half of the animals were to receive an exposure of 250 to 700 rads from Shot Hamilton. Lethality data in this exposure range is satisfactory for the probit analysis required to determine the LD_{50-30} .

The domestic pig was selected as the biological target, because this animal approximates man in cross-section and its response to radiation in the laboratory has been extensively studied. The pig was also the animal exposed during Operations Greenhouse and Plumbbob.

3.2.1 RBE Study. Three hundred and sixty swine were available for the LD_{50-30} experiment. They were divided into two major groups and stationed along the west and south axes. Ten stations of 13 animals each and five stations of 10 animals each were placed at 15-yard intervals along the west axis, ranging outward from a point at 170 yards from ground zero. A duplicate group of stations were placed along the south axis at 20-yard intervals, ranging outward from the 225-yard point (Figure 3.1). The multiplicity of stations was necessary in order to have the experimental plan cover the best-estimate yield range of 15 ± 10 tons. Three pigs at each 13-animal station were instrumented with internal gamma and neutron detectors. These 60 animals were also to be used for postshot hematology studies.

Animals were exposed in aluminum liners (Figure 3.2). When their size permitted, two pigs were placed in a liner. Because of the 30-day delay in Shot Hamilton, available swine varied greatly in weight, and by 15 October 1958 many exceeded 100 pounds. Animals weighing more than 85 pounds were exposed singly in the liners. Because of a limited number of liners, animals in the two most-distant stations from ground zero were placed in a line of woven-wire pens (36 inches high, 24 inches wide, and 44 inches long), divided one pig to a section. The closest of the pens was calculated to receive less than 0.7 cal/cm^2 of thermal radiation and less than 1 lb/in^2 overpressure, if the device achieved maximum yield. These thermal and blast effects were not expected to contribute to morbidity.

Animals were placed in the Frenchman Flat exposure area during the interval H - 8 to H - 4 hours. An average of 25 swine were transported in the bed of a standard 1½-ton truck.

After exposure, all animals were recovered and returned to assigned pens (one station to a pen) at the holding site. Ten animals from each station were reserved for the LD₅₀₋₃₀ study. Time-of-death observations were to begin immediately and were to continue at 4-hour intervals for 30 days.

3.2.2 Clinical Studies. A limited clinical program was planned. The radiation syndrome, including symptomology, body-weight changes, hematology, and pathology, has previously been documented in swine following gamma and X-radiation exposures. The primary objective was to determine if animals on the high-neutron-flux axis had a clinical course different from that for the animals on the low-neutron axis.

Clinical observations for vomiting, diarrhea, attitude, food and water consumption, etc. were to be made on all surviving animals at least twice daily. All swine were weighed on D - 1 day and were to be followed on the third, seventh, tenth, fourteenth, and twenty-first days after radiation. Commercial "Way-O-Crates" minimized handling.

Hematology studies using standard laboratory techniques and the pinhead white blood cell count method were done before exposure on the three internally dosimetered animals at each station and were to be done on the second, fourth, sixth, eighth, and tenth days following radiation. Only dosimetered animals were to be evaluated, because handling trauma can contribute to morbidity. The frequency of further studies was to depend on the early results.

A necropsy was to be performed as soon as feasible following death of each animal to determine the cause of death. The harvesting of tissue samples was held to a minimum to avoid duplication of the exacting techniques carried out during Operation Plumbbob.

3.2.3 Laboratory Study. As a control, a group of 60 swine of similar age and size and obtained from the same source as the NTS animals were to be exposed to X-radiation at the same time that swine were exposed to the nuclear detonation. These 60 swine were to be an LD₅₀₋₃₀ laboratory study by the Veterinary Division, Walter Reed Army Institute of Research (WRAIR). They were exposed, in groups of 10, to levels of radiation designed to bracket the middlethal dose of approximately 500 r.

Because of the delay in Shot Hamilton, this control group had to be exposed prematurely because of their weight gain. The animals were exposed 29 September 1958 using the Van de Graaff unit at the National Institutes of Health, Bethesda, Maryland. Beam characteristics included: operating voltage, 3.0 Mvp (megavolts, peak); target, gold (transmission); inherent filtration, 3-mm stainless steel; HVL (half-value layer), 21 cm in masonite phantom; TSD (target skin distance), 180 cm; and dose rate, 160 r/min.

3.3 RESULTS

The yield of Shot Hamilton failed to approach even the minimum yield for which the experiment was designed. Swine exposed received insignificant total body radiation. Free-air dose on the four stations nearest to ground zero on both the west and south axes ranged from a high of 230.5 rads to a low of 84.4 (Table 3.1). In an effort to evaluate the biological effects, animals at these four stations were studied clinically for 14 days after irradiation. There were no deaths among the experimental animals, and no clinical symptoms attributed to radiation injury. Body weights taken every other day beginning on D + 1 day demonstrated the gradual gain expected of swine on a maintenance ration (Table 3.2). Peripheral white

blood counts, using the standard chamber-counting method, demonstrated significant reductions, reaching a low point at D + 4, and appreciable recovery by D + 12 (Table 3.3).

The control-study swine, exposed to 3-Mvp X-radiation, were evaluated for the 30-day post-irradiation period. Analysis of the mortality data (Table 3.4) by the method outlined in Reference 40 indicates an LD₅₀₋₃₀ of 450 r, with 95-percent confidence limits of 365 and 450 r. The peripheral white blood counts are recorded in Table 3.5 and the average body weights in Table 3.6. It should be noted that this LD₅₀₋₃₀ for X-radiation is similar to that determined for nuclear-detonation radiation during Operation Plumbbob.

TABLE 3.1 INITIAL AIR DOSES (RADS), SHOT HAMILTON

Station	West Axis				South Axis			
	Distance yards	Gamma *	Neutron †	Total	Distance yards	Gamma *	Neutron †	Total
I	170			230.5	225			170.8
II	185			190.3	245			133.7
III	200			160.9	265			106.6
IV	215			132.4	285			84.4
V	230			112.3	305			69.6
VI	245			94.1	325			57.5
VII	260			81.8	345			47.72
VIII	275			70.4	365			42.9
IX	290			61.8	385			33.34
X	305			53.95	405			28.6
XI	320			48.1	425			23.98
XII	335			42.1	445			21.0
XIII	350			37.75	465			18.2
XIV	365			33.9	485			15.7
XV	380			31.37	505			3.7 ‡

* Table A.2. † Figure A.15. ‡ Figure A.14. § Extrapolated from curve, Figure A.15.

TABLE 3.2 AVERAGE BODY WEIGHT

Station	Distance	Average Weight*				
		D + 1	D + 3	D + 5	D + 7	D + 12
	yards					
West						
I	170	70.3	70.3	72.3	74.7	78.8
II	185	73.5	74.6	79.5	77.2	80.9
III	200	67.7	67.5	68.2	71.7	75.1
IV	215	64.0	64.4	66.6	69.6	77.7
South						
I	225	70	69.7	70	70	74.1
II	245	73	75.6	72.9	76.4	79.8
III	265	72.8	74.4	76.3	74.4	78.6
IV	285	73.8	73.7	75.6	76.4	80.3

* Mean of 13 animals

TABLE 3.3 WHITE BLOOD CELL COUNT, PERCENT OF PRE-EXPOSURE COUNTS

Station	Distance	White Blood Cell Count*				
		D + 2	D + 4	D + 6	D + 8	D + 12
	yards					
West						
I	170	39.5	28.3	60.0	53.0	58.0
II	185	40.5	34.3	38.0	51.0	38.0
III	200	49.3	46.0	81.6	47.5	61.5
IV	215	56.0	55.5	91.1	62.2	75.0
South						
I	225	62.2	52.6	70.0	64.8	54.0
II	245	50.0	56.5	67.6	83.0	60.0
III	265	80.6	93.2	100.0	100.0	100.0
IV	285	65.5	100.0	100.0	100.0	100.0

* Mean of 3 animals

TABLE 3.4 MORTALITY IN X-IRRADIATED SWINE

Dose*	Mortality†	Survival Time‡
r		day
355	4/10	16.4 ± 0.8
425	5/10	14.8 ± 1.3
505	9/10	15.2 ± 1.4
600	9/10	13.2 ± 1.0
720	10/10	12.5 ± 0.5

* Bendix ion-chamber measurement in air at mid-point of pig.

† Number of dead over number exposed.

‡ Mean ± standard error of mean.

TABLE 3.5 WHITE BLOOD CELL COUNT, PERCENT OF PRE-EXPOSURE COUNTS, OF X-IRRADIATED SWINE

Dose	White Blood Cell Count*						
	D + 2	D + 4	D + 7	D + 10	D + 14	D + 21	D + 30
r							
355	50.4	40.9	52.0	34.5	31.4	40.0	62.0
425	74.5	29.4	33.1	28.0	32.1	50.3	51.6
505	48.6	32.6	38.1	27.8	23.7	53.8†	46.8†
600	42.1	30.0	24.0	15.5	37.4	143.5†	80.5†
720	57.8	26.5	20.4	12.6	17.3†	—	—
0	90.8	109.2	122.6	100.1	109.3	116.4	100.5

* Mean of survivors

† Small number of animals

TABLE 3.6 AVERAGE BODY WEIGHT (POUNDS) OF X-IRRADIATED SWINE

Dose	Average Body Weight*						
	D + 2	D + 4	D + 7	D + 10	D + 14	D + 21	D + 30
r							
355	76.2	76.0	75.9	83.4	80.9	77.8	78.8
425	74.9	72.0	75.2	81.1	73.9	78.4	77.6
505	76.0	74.8	76.8	78.3	80.8	46.5	53.0
600	77.2	76.0	78.4	76.2	59.5	47.0	49.0
720	80.1	77.9	81.9	81.1	55.0	—	—
0	72.8	74.8	76.8	82.9	89.1	90.6	90.6

* Mean of survivors

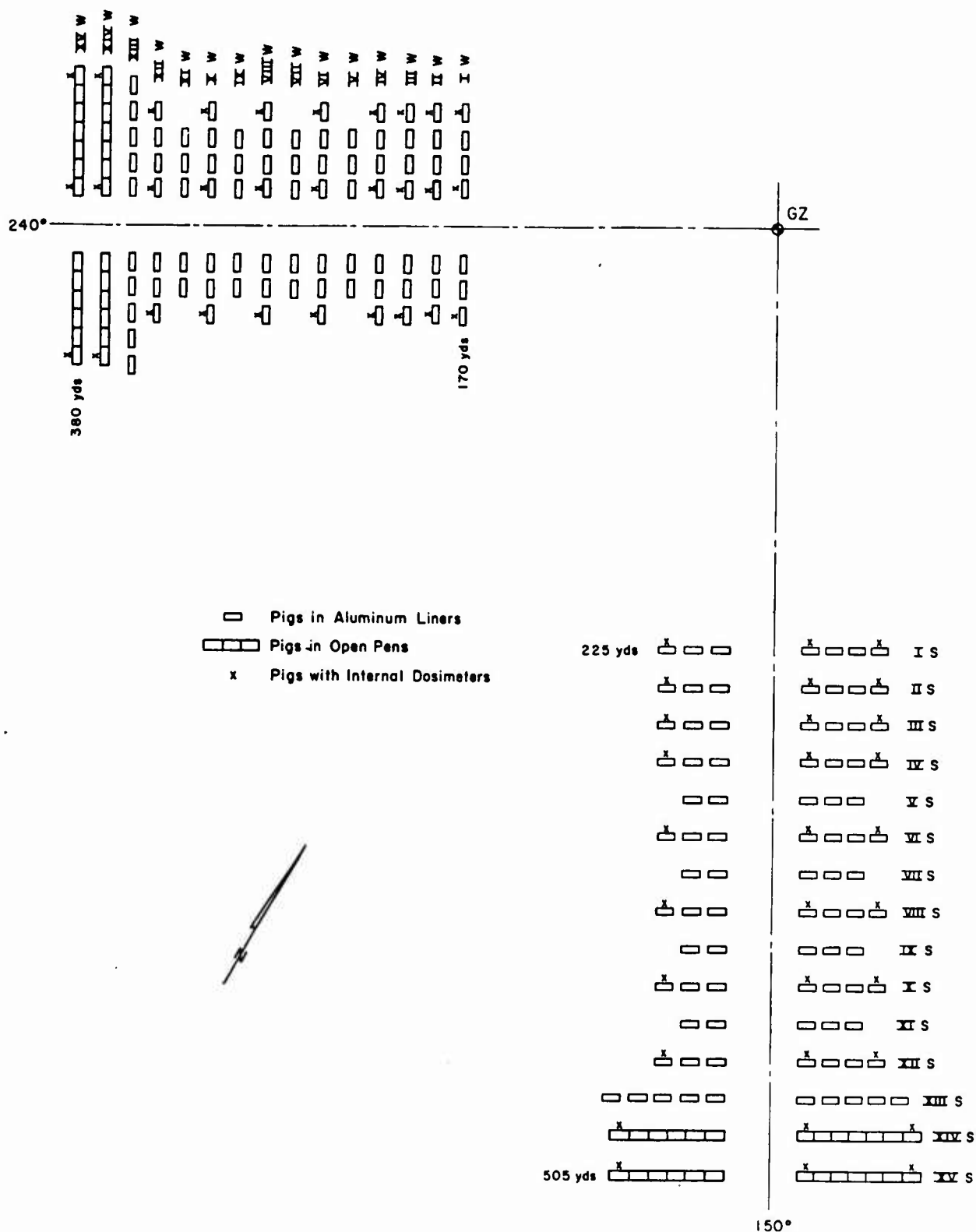


Figure 3.1 Large animal (swine) exposure stations; Shot Hamilton.

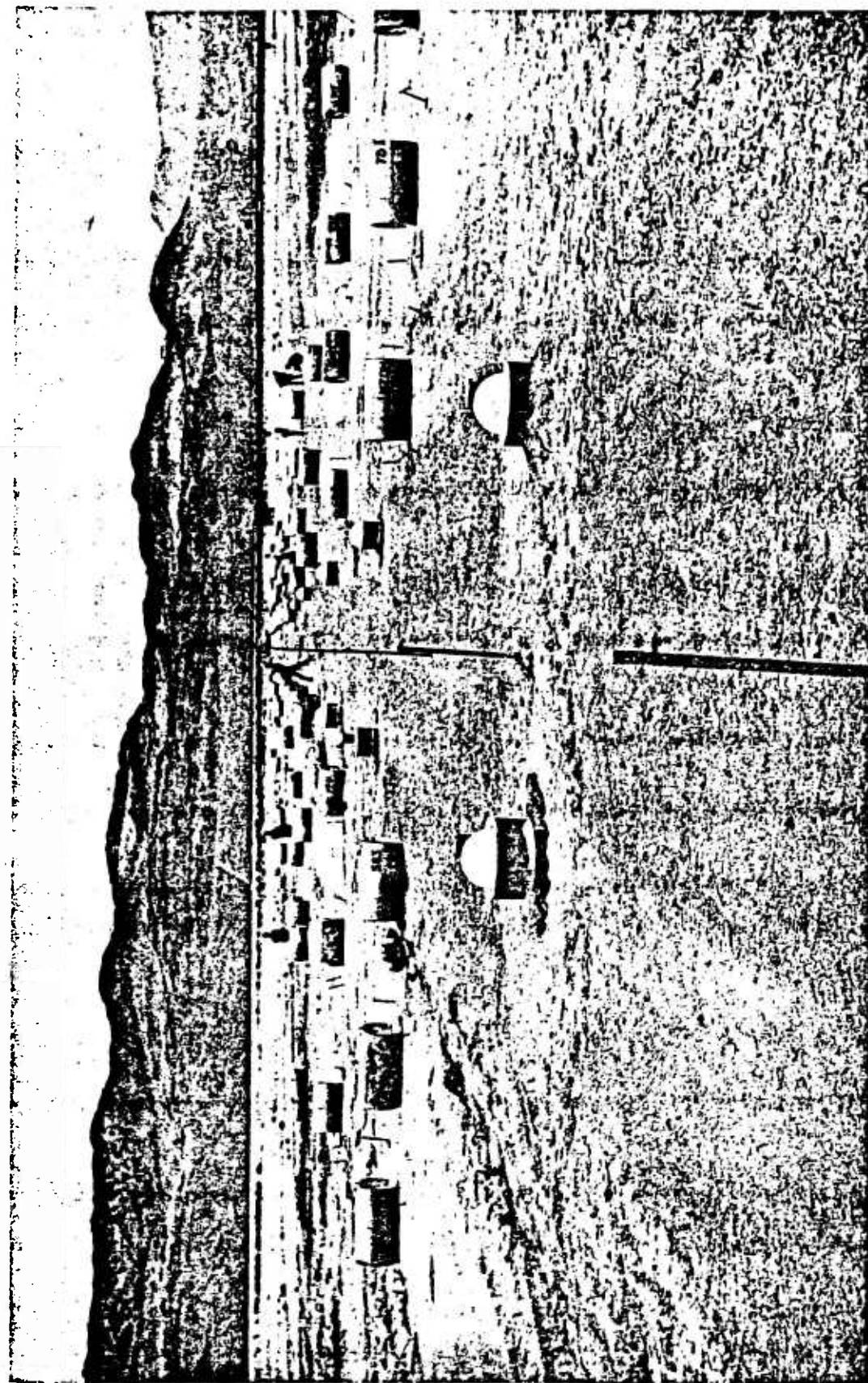


Figure 3.2 Aluminum liners for swine, south axis, Shot Hamilton.

Chapter 4

SMALL ANIMAL (MICE) RESPONSE TO WEAPON RADIATION

4.1 INTRODUCTION

Mice were exposed during Shot Hamilton to provide an additional RBE measurement for comparative purposes with the swine, based on several well-characterized rodent responses to whole-body X-radiation.

4.2 MATERIALS AND METHODS

Six weeks before the detonation of the Hamilton device, 3,000 female mice (Walter Reed Bagg strain, 3 to 5 weeks of age) were flown to NTS and housed in a small-animal unit. The response of this strain to laboratory X-ray (250 kvp) is well known. On D - 7 days, 1,690 mice weighing 22 to 35 grams were selected for the various experimental procedures. On D - 1 day, the mean weight of the mice used in the RBE experiment was 28.6 grams.

Lead and aluminum hemispheres had been used extensively in previous field tests, and the technique used on Shot Hamilton was exactly as described in References 28 and 41. The lead hemispheres reduce the inside-air gamma dose to essentially zero

Aluminum hemispheres and liners offer no significant reduction in either the gamma or neutron radiations as measured in free air (Reference 28).

Mice to be exposed in the various types of hemispheres were randomly selected and dyed with picric acid to identify the several subgroups. Three separate exposure lines were established on two axes from the device (Figures 4.1 and 4.2). The first, a line of 15 lead hemispheres (S-1 through S-15), was located on the south axis and so placed that a

A line of 13 aluminum hemispheres (S-16 through S-30) was placed to cover the same dose range (S-29 and S-30 were aluminum liners rather than aluminum hemispheres). On the west axis, there was a total of 12 aluminum hemispheres (W-1 through W-12) and three aluminum liners (W-13 through W-15) covering the same dose range. One aluminum hemisphere was installed at the animal-holding facility to stress controls equally but without radiation.

Table 4.1 shows the preshot percentage estimates of the gamma and neutron dose. After the shot, a similar group of mice was to be exposed to a 250-kvp X-ray source with measurements of the same indices at WRAIR. In this manner, four mixtures of gamma and neutron flux delivered to similar animals were to be assessed and the RBE for varying proportions of the radiations determined. The postexposure evaluation schedule of the animals is also shown in Table 4.1. Half the animals were to be followed for 30-day survival to calculate the LD_{50-30} . Body weight loss over this time would also be determined. At H + 72 hours, the following measurements were to be made: (1) total-body weight loss, based on body weight 24 hours before the detonation, expressed as percentage change; (2) wet-spleen weight loss; and (3) formalin-fixed thymus weight loss.

Animals selected for serial sacrifice were to be used for frequent peripheral white-blood-cell (WBC) counts and a count of the total number of marrow cells contained in the right femur. The total white-cell count was to be done in the conventional manner using tail blood. The marrow-counting procedure is described in Reference 42. These studies were preliminary in nature and designed to provide estimates of the total dose received, the pattern of recovery, and the probability of 30-day survival.

4.3 RESULTS

Stations S-1 through S-15 received (Table 4.2); S-16 through S-30 received (Table 4.3); and W-1 through W-15 were exposed to only

Table 4.4). Beginning at H + 72 hours, 10 control mice were sacrificed for baseline weight loss, wet-spleen weight loss, and formalin-fixed thymus weight loss. With these figures established, the closest station on the lead hemisphere axis (S-1) was sacrificed as planned (Table 4.1). When two consecutive stations had wet-spleen weights and thymus weights not significantly different from the controls, the closest-in station of aluminum hemispheres (S-16) was sacrificed. As with the mice in the lead hemispheres, where two consecutive stations had wet-spleen and thymus weights not significantly different from the controls, the next axis of hemispheres was sacrificed starting with the closest station.

Table 4.5 presents the weight loss, in percent, based on the body weight 24 hours before exposure. The value obtained is based on the average weight of 40 mice at each point. The few values at doses above are the highest obtained, as was expected. Below, however, the body weight loss has no visible relationship to dose. There is no indication that neutron rads are any more effective than gamma rads in producing body weight loss in the dose range below.

The serial sacrifice program was discontinued after D + 12, when it became obvious that negligible mortality would occur during the 30-day observation period. The lowest total white-cell count observed was 1,050 per cubic millimeter at Station W-2 on D + 3 days. The lowest marrow count was 1.4×10^6 nucleated cells, at Station W-1 on D + 2 days. Table 4.6 gives the results obtained through the period D + 12 days. Some of the scatter is due to the fact that on any one day only one mouse per station was sacrificed. A modest depression and trend to recovery can be made out, however, in both the peripheral blood count and the marrow count. The lag in peripheral-count recovery contrasted to marrow recovery has been noted (Reference 42). The data available does not permit an estimate of RBE for these specific hematopoietic indices.

Table 4.7 shows the 72-hour percentage weight loss of the spleen and thymus (based on control weight) in mice exposed to various mixtures of neutron and gamma radiation. Spleen weight loss due to neutron exposure is not different from that due to mixtures, as long as the total dose is the same. Thymus weight loss appears to be greater with neutron exposure alone. In both cases, however, the range covered is so small that no RBE should be determined.

4.4 DISCUSSION

The experiment was not successful, because the yield of Shot Hamilton failed to meet even the lower limit of experimental plan. No valid RBE could be calculated or even estimated for spleen, thymus, or body weight loss. A conclusive RBE should be based on the response over the range of 100 to 1,000 rads (Reference 43). The serial sacrifice program was also discarded after D + 12 days, because mice receiving the greatest exposure had recovered. It was expected that the 30-day mortality would be negligible; thus an LD₅₀₋₃₀

could not be obtained on any axis of exposure. On D + 13, all mice were sacrificed. There were no deaths in any of the groups of mice up to that time.

TABLE 4.1 PROTOCOL FOR RBE MOUSE EXPERIMENT, SHOT HAMILTON

Station	Estimated Dose		Assignment of Animals to Groups			
	Percent Incident Gamma	Percent Incident Neutron	30-Day Survival	72-Hour Sacrifice	Serial Sacrifice	Total
S-1 through S-15	0	100	20	10	—	30
S-16 through S-30	30 to 35	65 to 70	20	10	10	40
W-1 through W-15	65 to 70	30 to 35	20	10	10	40
Laboratory	100 pct X-ray	0	20	10	10	40

TABLE 4.3 EXPOSURE DOSE IN RADS IN ALUMINUM
HEMISPHERE STATIONS ON SOUTH AXIS

Station / Number	Total Rads in Hemisphere†	Distance from Ground Zero yards
S-16	219.1	210
S-17	159.7	230
S-18	125.3	250
S-19	100.25	270
S-20	81.06	290
S-21	66.35	310
S-22	56.6	330
S-23	45.4	350
S-24	36.15	370
S-25	32.0	390
S-26	27.7	410
S-27	23.63	430
S-28	19.91	450
S-29	16.88	470
S-30	14.63	490

* From Figure A.14.

† From Figure A.15.

‡ Total dose in hemisphere taken to be the same as air dose (Reference 2).

§ Extrapolated from Figure A.15. Detectors not recovered in time to yield data.

TABLE 4.4 EXPOSURE DOSE IN RADS IN ALUMINUM
HEMISPHERE STATIONS ON WEST AXIS

Station Number	Total Rads in Hemisphere†	Distance from Ground Zero yards
W-1	312	150
W-2	229.5	170
W-3	181.8	190
W-4	141.5	210
W-5	113.2	230
W-6	91.2	250
W-7	74.65	270
W-8	62.6	290
W-9	52.04	310
W-10	44.22	330
W-11	37.82	350
W-12	33.25	370
W-13	28.65	390
W-14	25.8	410
W-15	22.68	430

* From Figure A.14.

† From Figure A.15.

‡ Total dose in hemisphere taken to be the same as air dose (Reference 2).

§ Extrapolated from Figure A.15.

TABLE 4.5 72-HOUR PERCENTAGE BODY
WEIGHT CHANGE

Total Dose rads	Aluminum* Hemisphere (Low Neutron)	Aluminum* Hemisphere (High Neutron)	Lead† Hemisphere (100-percent Neutron)
312	-6.0	—	—
219	—	-4.2	—
229.5	-3.9	—	—
190	—	—	-1.0
159.7	—	-2.2	—
147.3	-2.3	—	-3.0
125.3	—	-2.0	—
141.5	-2.8	—	—
114	—	—	+2.8
100.25	—	-1.0	—
90.4	-0.7	+1.4	-1.4
76	+0.3	-1.0	-2.1
60	-0.7	-3.0	-3.4
50	-0.8	-0.7	+0.4
Controls	-2.5	—	—

* Averages of 40 animals. † Averages of 30 animals.

TABLE 4.6 HEMATOPOIETIC RESPONSE OF FEMALE MICE

Station	Total Dose rads	1 Day After Exposure		2 Days After Exposure		3 Days After Exposure		4 Days After Exposure		6 Days After Exposure		8 Days After Exposure		10 Days After Exposure		12 Days After Exposure	
		WBC* marrow†	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow	WBC marrow
S-16	219	2.65	2.7	2.00	2.9	3.10	—	1.65	3.5	2.35	3.3	4.15	—	2.05	—	6.40	—
S-17	160	2.70	4.6	2.65	3.3	3.00	—	1.95	7.1	2.15	5.5	3.00	—	4.95	—	11.85	—
S-18	125	3.05	4.4	2.65	2.9	1.45	—	1.40	7.2	2.94	9.2	9.50	—	4.00	—	8.15	—
S-19	100	—	—	—	—	1.85	—	—	8.8	3.40	9.5	11.80	—	3.60	—	5.90	—
S-20	81	—	—	—	—	3.15	—	—	9.2	—	—	—	—	—	—	—	—
S-21	66	—	—	—	—	3.35	—	—	12.4	—	—	—	—	—	—	—	—
W-1	312	1.9	4.7	1.60	1.4	2.10	—	1.45	4.6	1.35	12.3	2.95	—	3.15	—	7.65	—
W-2	229	2.4	5.9	1.45	3.6	1.05	—	1.75	6.2	4.75	5.6	1.65	—	3.85	—	8.40	—
W-3	182	2.6	5.1	2.35	3.2	2.75	—	3.20	6.8	3.65	8.6	5.25	—	4.20	—	8.05	—
W-4	141	—	—	—	—	4.00	—	—	11.7	2.65	11.8	6.60	—	6.50	—	7.45	—
W-5	113	—	—	—	—	4.00	—	—	7.7	—	—	—	—	—	—	—	—
W-6	91	—	—	—	—	4.40	—	—	6.4	—	—	—	—	—	—	—	—
Control	0	17.35	6.7	7.25	16.1	5.15	—	8.80	8.4	10.90	12.5	11.5	—	9.55	—	7.25	—

* Value listed is in thousands of cells per mm³. † Value listed is total number of nucleated cells $\times 10^6$ per right femur.

TABLE 4.7 PERCENT WEIGHT LOSS, SPLEEN AND THYMUS, 72 HOURS POSTEXPOSURE

Radiation Dose, rads		Spleen		Thymus	
Neutron	Gamma	Total	Mixtures Neutron	Mixtures Neutron	Neutron
71	—	—	—	—	54
71	12	—	—	21	—
88	0	—	—	26	—
90	—	13	—	—	65
108	15	—	—	34	—
113	14	—	—	47	—
114	—	10	—	—	47
135	30	—	—	55	—
141	36	—	—	40	—
147	—	37	—	—	77
172	55	—	—	63	—
181	42	—	—	59	—
190	—	55	—	—	79
225	34	—	—	75	—
229	58	—	—	70	—
312	61	—	—	74	—

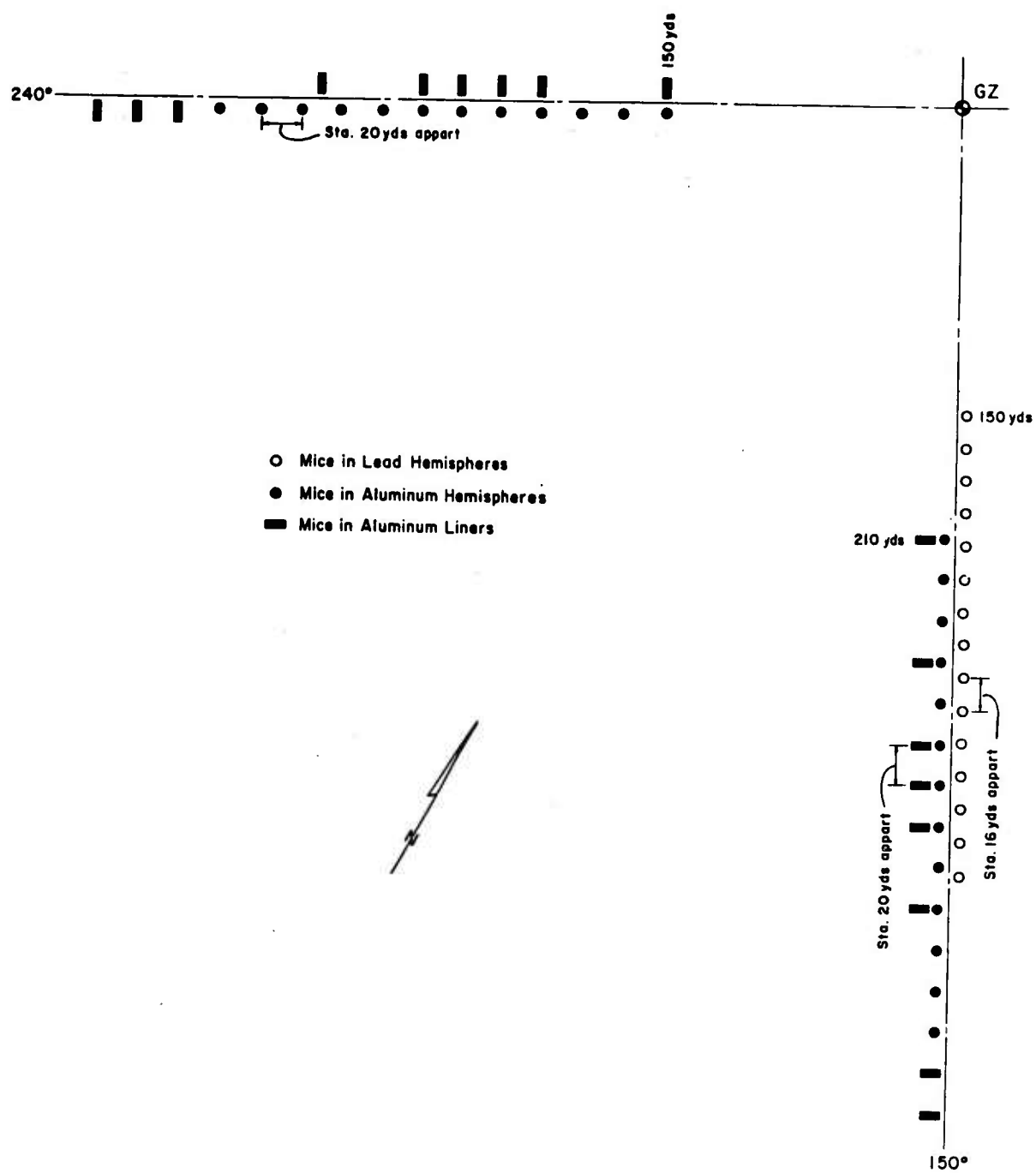


Figure 4.1 Small animal (mice) exposure stations;
Shot Hamilton.



Figure 4.2 Lead hemispheres in foreground and aluminum hemispheres in left background, Shot Hamilton.

RADIATION PRE-PROTECTION WITH AET

5.1 INTRODUCTION

Pre-protection chemical agents had never been tested against the radiation delivered by a nuclear detonation. Because oral administration of AET was feasible (sufficient time was available for the procedure to be done within the safe time limits for animal placement), additional stations were set up on both the south and west axis of the Subproject 4.2.3 array (Figure 4.1). These contained AET-treated mice and appropriate controls.

5.2 MATERIALS AND METHODS

A total of 870 female mice, Walter Reed Bagg strain, were used. The mean weight was 28.6 grams, range 22 to 35 grams, and the age 9 to 11 weeks. All treated mice received 25 mg of AET (dibromide salt weight), given by gastric tube in 0.5 ml of an M/15 phosphate buffer, pH adjusted to 7.5. The average dose was 875 mg/kg. The AET treatment was scheduled to start at H-5 hours. The dose of AET given was expected to cause no more than 5-percent mortality within 24 hours.

On the south axis, Stations S-1 through S-15 (lead hemispheres) each contained 10 treated mice. Stations S-31 through S-34 and S-A and S-B (aluminum liners) were located so that at least two of them would receive about This is the 100 percent, 30-day-lethal dose for this mouse strain (Reference 44). On the west axis, W-16 through W-19, W-A and W-B were located to cover the same dose range. Each liner contained 60 mice, 20 to a cage. Half were given AET and the remainder received only the buffer in which the AET was dissolved.

Postshot evaluation of the mice was to consist entirely of survival studies in Stations S-1 through S-15. The remaining stations were to have 20 AET-treated mice and 20 controls for a 30-day-survival study. In addition, 10 in each group were to be serially sacrificed on a random basis over the 30-day period to measure possible changes in organ weight. Unfortunately, as far as is known for at least 5 days after radiation, there is no biological measure which will demonstrate differences between treated and control animals (Reference 33).

5.3 RESULTS

Because of late indecisions on the precise time of Shot Hamilton, gastric intubation of the mice was not started until H-3.5 hours. Therefore, Stations S-13, S-14, S-15, and S-31 had to be omitted. Intubation could not begin until a firm detonation time was available. Twenty-four hours after exposure, 15 percent of the AET-treated mice were dead. This was undoubtedly caused by a combination of drug toxicity and trauma due to haste.

The closest station, W-16, received a dose of 321.5 rads, gamma plus neutrons; S-1 received 190 rads total. All others received less than 200 rads (Tables 4.2 and 5.1). These

levels of radiation do not result in mortality in 30 days.

Because of the low dose delivered to most of the stations, the serial sacrifice program was not carried out. Daily observations and calculation of the 72-hour weight loss were recorded. On D + 13, all mice were sacrificed. Up to this time there had been no deaths except in those treated with AET (none were expected).

Table 5.2 shows the body weight changes as a function of the radiation dose of AET-treated mice as compared to their controls. For the sake of clarity, total doses at the various stations that varied by less than 10 rads are averaged. For example, the total dose of 72 rads is the average for three stations of 67, 71, and 77 rads. There is no clear relationship. The AET mice in general seem to have lost less weight. This is probably due to the fact that early drug toxicity mortality was confined largely to the lighter mouse population, thereby distorting the average values obtained after exposure.

5.4 DISCUSSION

The experiment was a failure, because radiation delivered in the field was below lethal levels.

TABLE 5.1 AIR EXPOSURE DOSE IN RADS AT AET-TREATED STATIONS

Station Number	Air Gamma *	Air Neutron †	Total Rads in Liner ‡	Distance from Ground Zero yards
West Axis:				
W-16			321.5	150
W-17			145.4	210
W-A			114.9	230
W-B			92.0	250
W-18			76.5	270
W-19			53.5	310
South Axis:				
S-32			100.2	270
S-A			66.9	310
S-33			54.7	330
S-B			42.6	350
S-34			31.5	390
S-1 through S-12	See Table 4.2 for these values			

* From Figure A.14.

† From Figure A.15.

‡ Total dose in liner taken to be same as air dose (Reference 1).

Chapter 6

SUMMARY

The less-than-predicted yield of Shot Hamilton resulted in such small radiation doses that none of the objectives were achieved.

Limited participation on Shot Humboldt demonstrated that initial nuclear radiation doses in excess of 85,000 rads, gamma plus neutrons, were insufficient to cause immediate lethality in swine protected against blast and thermal. Higher levels of radiation to swine were achieved only in open foxholes, but here the environment was destroyed by the blast. No conclusions could be drawn as to cause of death in animals exposed in such foxholes.

To evaluate immediate lethality under the experimental plan, personnel had to contend with significant levels of radiation from the nuclear detonation.

It appears that measurement of neutron-induced Na^{24} activity in the blood is a feasible method for estimating the neutron dose received (Appendix B).

A report on air sampling for Shot Hamilton is given in Appendix C.

Appendix A

DOSIMETRY

The ultimate objective of the dosimetry program was to acquire a complete set of physical data that would permit specific correlation between the radiation dose delivered and the biological response observed in the experimental animal. Because of qualitative and quantitative limitations of both biological measurement and of dosimetry techniques presently available, this ideal could not be attained, but methods and operational plans were directed toward this goal.

Extensive support was provided by other projects in making available a number of types of dosimeters. Some of these were developmental, whereas others had been well tested in previous detonation.

Because of numerous technical difficulties encountered, it was not possible to obtain final corrected data from all agencies. Such corrected data was prepared by Project 2.12 (Reference 45) and is used exclusively in this report. The use of the data and the exclusion from the final report of all other data are necessary simplifications in the interest of clarity and consistency. This decision does not necessarily imply that other data is unreliable, but of the data obtained by agencies other than Project 2.12 much is either incomplete or uncorrected. For technical and administrative reasons, it is not possible to improve the data. For those who may be interested, the preliminary data from all supporting agencies is on file at the Walter Reed Army Institute of Research, Washington 12, D. C.

The exception to the above decision is the use of neutron flux data obtained by the Los Alamos Scientific Laboratory (LASL) on the west line for Shot Hamilton. No other neutron data is available on this line. Preliminary corrections have been made although the data cannot be considered final (Reference 46).

Project 4.2 furnished administrative support for the evaluation of the U. S. Navy DT-60 dosimeter under field-type conditions. The dosimeter was evaluated as to its reproducibility and accuracy of gamma, X-ray and thermal, and fast-neutron responses. This effort is reported in Reference 47.

A.1 BACKGROUND AND THEORY

Considerable experimental work has been done in the field and in the laboratory in an effort to measure separately the air dose and absorbed dose from gamma and neutron radiations. An all-inclusive technique, adaptable to field use and of acceptable accuracy and consistency, has yet to be demonstrated. More success has been obtained in the measurement of gamma radiation than in the case of neutron flux, but there remain many unsolved problems, not the least of which are reproducibility from one laboratory to another, considerable logistical support for field application, and the single ideal dosimeter that would be separately responsive to gamma and neutron radiations.

A.1.1 Gamma Dosimetry. Project 2.12b placed National Bureau of Standards (NBS) film badge holders containing DuPont 553 film for low range (0 to 2,500 r) and Eastman special order film for the high range (2,500 to 50,000 r). Where neutron data were available, the film badge readings have been corrected for neutron response, neutrons contributing at least 10 percent and occasionally as high as 400 percent to the measured gamma dose.

A.1.2 Neutron Measurements. Neutron measurements were accomplished by Project 2.12a, employing the first threshold detector technique. Neutron dose was calculated from the neutron flux values using the single-collision theory of dose contribution per neutron (Reference 48). The following equation was used in the calculation of neutron dose from the neutron flux data:

$$\text{Dose (rep)} = \left[1(N_{\text{Pu}} - N_{\text{Np}}) + 2.5(N_{\text{Np}} - N_{\text{U}}) + 3.2(N_{\text{U}} - N_{\text{S}}) + 3.9N_{\text{S}} \right] 10^{-8}$$

Where: N_{Pu} = flux above Pu threshold

N_{Np} = flux above Np threshold

N_{U} = flux above U threshold

N_S = flux above S threshold

The coefficients used were determined by taking the dose per neutron at the mean energy between the threshold energies of the successive detectors. No gold term is included in the equation above, because the dose contribution of the neutrons measured by the gold detector was insignificant. Because of the limited number of complete fission foil systems, in general the neutron data must be taken from the curves constructed on the basis of the points measured.

A.2 MATERIALS AND METHODS

A.2.1 Shot Hamilton. Project 2.12a provided neutron measurements on a cable at 25, 50, 75, 100, 125, 150, 200, 300, 400, 600, and 800 yards on the north axis and at 15, 35, 80, 225, and 325 yards on the south axis. West axis neutron dosimetry by LASL was obtained by the same method (the threshold detector techniques) on a goalpost line at 100, 200, 300, 400, 500, and 600 yards down the midline of the exposure array (Figure A.1).

Dosimeters were also placed in all five tanks, in the two APC's, in four offset foxholes, and in four open foxholes (Figure 2.9).

Project 2.12b measured gamma dose employing NBS film packets in holders at those distances from 25 through 800 yards on the north and south axes paralleling the neutron dosimetry and on the west axis at 100-yard intervals, 100 through 700 yards. Additional film packets were placed in tanks, APC's, and in each of the three types of foxholes. These dosimeters were also extensively placed at safe-user pens and adjacent to the stations of Subproject 4.2.3 (Figure 4.1).

Placement of all dosimeters was accomplished by H-10 hours. All dosimeters exposed to potential overpressures in excess of 50 psi were contained within blast shields, fabricated from aluminum, or improvised from steel pipe and fittings.

In order to provide specific data on the geometry of dosimeter placement by Project 4.2 personnel, the following detailed description of the geometry is presented. (A description of the types of foxholes is given in Chapter 2.)

Offset foxholes. To facilitate recovery, the dosimeters in offset foxholes were attached to cotton clothesline of sufficient length to reach a marking stake at the exterior of the fortification. The dosimeters were then placed at the extreme rear of the tunnel on the floor. In four of the offset foxholes, Hurst complete fission foil (HCFF) systems were affixed to a 36-inch steel rod, which was placed on the floor at the extreme rear of the tunnel.

Two-thirds-closed foxholes. The dosimeters were attached to a 36-inch steel stake driven 18 inches into the floor of the foxhole. The height of the dosimeter was 14 inches above the floor. The stake was located against the right wall of the foxhole, facing ground zero, and geometrically in its center (Figure A.2).

Open foxholes. Dosimeters were placed as for two-thirds-closed foxholes (Figure A.3).

Tanks. All dosimeters were attached to a short steel cable suspended vertically from the hatch so that they were immediately adjacent to the animal placed in the driver's seat (Figure A.4).

APC's. The dosimeters were suspended adjacent to the driver's seat, as described for the tanks (Figure A.5).

Open pens. Dosimeters were affixed to the front surface of steel stakes facing ground zero or to the steel stakes supporting the pens (Figure A.6).

All dosimeters associated with the Subproject 4.2.3 axes on the west and south were mounted on steel stakes driven into the earth adjacent to each end of the exposure station (Figure A.7).

Dosimeters for the goalpost lines were mounted in a standard manner on the goalpost crossbars. These lines consisted of seven stations on the north at 25-yard intervals from 25 through 175 yards, seven stations on the west at 100-yard intervals from 100 through 700 yards, and eight stations on the south at 100-yard intervals from 100 through 800 yards.

Blast protection for the film packet holders are shown in Figures A.8 and A.9.

A.2.2 Shot Humboldt. Dosimeters were placed on a single, east axis from ground zero for the event (Figure A.10). Free-air neutron and gamma dosimeters were attached to a cable (Project 2.12) along the central axis of the station array. Dosimetered points were at 10, 25, 50, 100, 200, and 300 yards (ground range) from ground zero. Additional free-air gamma dosimetry was placed on stakes and goalposts to a distance of 800 yards.

Ten foxholes, two on each line, were instrumented by gamma and neutron dosimeters attached to extensions from the middle-axis cable into the foxhole. The instrumented foxholes were those immediately adjacent to the dosimeter axis. The dosimeters lay on sandbags approximately 3 feet below the surface of the earth

against the wall of the foxhole nearest the axis. In general, the dosimeters were centrally located in the hole with respect to the east-west direction (Figures A.11 and A.12).

The two APC's had film badge gamma dosimeters in three positions inside the vehicle (front, middle, and rear). A complete fission foil system was placed within each APC at its center, 4 feet above the floor. Blast protection was provided as for Shot Hamilton (Figure A.13).

A.3 RESULTS

A.3.1 Shot Hamilton. All but 20 dosimeters were recovered by H + 30 hours, and by H + 90 hours, 100 percent recovery was effected. At recovery, all dosimeters were found to be in their original positions and showed no external evidence of damage.

Tables A.1 through A.6 present initial gamma and neutron measurements for the Hamilton event. Figures A.14 and A.15 present appropriate plots of these data. The contribution of the residual (induced) gamma is not considered to be significant despite the delay in recovery of some dosimeters, because the device yield was well below the anticipated level.

Because of the delayed recovery of the threshold detectors in the offset foxholes, the large neutron shielding effect of these fortifications, and the low weapon yield, decay of these foils had progressed beyond countable levels by the time of recovery. As a result no readings were obtained for neutron dose in these positions.

A.3.2 Shot Humboldt. All but one of the dosimeters were recovered by H + 1 hour. The use of the cable line, towed out immediately after the shot, made this possible. Residual (induced) gamma radiation was thereby minimized and is not considered to have contributed significantly to the gamma doses measured.

Table A.7 presents the results of free-air measurement of initial gamma and neutron radiation. Figures A.16 and A.17 are plots of data in Table A.7. No attempt has been made to plot the data presented in Table A.8, internal foxhole dosimetry, because of complexities of shielding and orientation. The slant ranges given in Table A.8 were calculated from tower height, ground distance, and distance of the dosimeter off the surveyed axis, taking into consideration the height above or depth below the surface of the earth of the dosimeter.

A.4 DISCUSSION

The results presented are, in general, consistent and represent the most reliable dosimetry presently available for field application. One of the ancillary objectives of the project was the evaluation of the many different systems of gamma and neutron dosimetry that had been developed up to the time of the project. Toward this objective, a large number of dosimeters of many kinds were actually placed, usually side by side. Unfortunately, it was necessary after final analysis to abandon this objective because of lack of corrected data from supporting agencies other than Project 2.12. Certain pertinent conclusions can nonetheless be drawn. Presently available methods and techniques of dosimetry, both in the laboratory and in the field, leave much to be desired. The complexities of spectral distribution of the radiation, be it gamma or neutron, plus the lack of an accurate means of measuring absorbed dose force the investigator to indirect methods, which add further variables to an already formidable problem. Indeed, even the basic units of dosage continue to undergo change at the definition level.

Only fair agreement was observed among the several systems employed. Cross calibration among the systems, in most instances, has not been accomplished. Gross inconsistencies were so numerous as to obviate analysis.

Attempts to evaluate the RBE for death for device neutrons have thus far failed, primarily because the use of experimental devices has precluded accurate prediction of dose versus range. In any case, the problem of inconsistent dosimetry might still have prevented a reliable answer.

It is for these reasons that this report has been greatly simplified by the presentation of data from a single agency. Evaluation of means and methods of dosimetry are not considered to be within the scope of the study or the capability of the authors. But it is clear that until reproducible dosimetric results by more than one method can be demonstrated in the laboratory and in the field, the radiobiologist cannot hope to correlate physical dose with biological response.

Among the many variables that must be taken into account in explaining and in interpreting results is that of backscatter and shielding at the site of the dosimeter. Hence, the doses measured at the driver's seat in the tanks and APC's are misleading at first glance. The large differences in dose at similar distances from the device are at least partly explained by the orientation of the vehicles.

Table A.9 was obtained by correcting all observed doses by the inverse square attenuation so that all vehicles are considered to be at the same distance, namely, 50 yards from the device. Ignoring air absorption, the only remaining variable is shielding and scatter. It is noted from the table that these theoretical doses agree fairly well for the two APC's, both with side-on orientation, for Tanks 67 and 69 as a second

group, and Tanks 65, 68, and 70 as a third group, the criterion being similar orientation. Thus the importance of the shielding as well as the fair consistency of the data is demonstrated. A similar analysis might be applied to the foxhole fortification but would be much more involved.

Because the RBE for device neutrons, with lethality in large animals as the endpoint, is still undetermined, some arbitrary convention is required if any addition of the gamma and neutron doses is to be made in order to depict a total dose. As long as only the incident, or air dose, is considered and no inference to absorbed dose is either intended or permitted, it appears reasonable to express both the gamma and neutron dose in the same units and to simply add them arithmetically to obtain the total dose incident upon the position or point in question. The rad was chosen arbitrarily as the common unit, and the following relationships were assumed: (References 49, 50, and 51)

$$1 \text{ r} \approx 87 \text{ ergs/gm in air}$$

$$1 \text{ rep} \approx 95 \text{ ergs/gm in air}$$

$$1 \text{ rad} \approx 100 \text{ ergs/gm in air}$$

Hence, in order to convert roentgens to rads,

$$(1) \frac{87 \text{ ergs/gm}}{\text{r}} + \frac{100 \text{ ergs/gm}}{\text{rad}} =$$

$$(2) \frac{87 \text{ ergs/gm}}{\text{r}} \times \frac{\text{rad}}{100 \text{ ergs/gm}} =$$

$$(3) \frac{87 \text{ rad}}{100 \text{ r}}$$

$$(4) \therefore 1 \text{ rad} = \frac{100}{87} \text{ roentgen}$$

and to convert roentgens to rads, multiply by 0.87

$$(5) \text{ Number of rads} = 0.87 \times \text{number of roentgens.}$$

In like manner to convert air reps to air rads, multiply by 0.95,

$$(6) \text{ Number of rads} = 0.95 \times \text{number of reps.}$$

TABLE A.1 INITIAL GAMMA RADIATION, SURFACE STATIONS,
SHOT HAMILTON

Project 2.12b, NBS film badge.

Station Number	Slant Range	Dose		
	yd	r	rads	
25N	30.2	~1,800	~1,560	
50N	52.8	1,700	1,480	
75N	76.9	540	470	
100 N, S, W	101.3	350	305	
125 N	126	210	182	
150 N	150	140	161	
175 N	175	94	82	
200 W, S	200	67	58	
300 W, S	300	22	19	
400 W, S	400	9.4	8.2	
500 W, S	500	4.5	3.6	
600 W, S	600	2.3	2	
700 W, S	700	1.3	1.1	
800 S	800	0.73	0.64	

TABLE A.2 INITIAL GAMMA MEASUREMENTS, SURFACE STATIONS, SHOT HAMILTON

Project 2.12b, NBS film badge.

South Line				West Line			
Station Number	Slant Range	Dose		Station Number	Slant Range	Dose	
	yd	r	rads		yd	r	rads
I	225	49	42.6	I	170	101	88
II	245	39	34	II	185	82	71.5
III	265	32	27.8	III	200	67	58.4
IV	285	26	22.62	IV	215	55	47.9
V				V			
VI	325	18	15.67	VI	245	39	33.9
VII				VII			
VIII	365	12	14.4	VIII	275	28	24.4
IX				IX			
X	405	9.0	7.73	X	305	21	18.3
XI				XI			
XII	445	6.7	5.84	XII	335	16	13.9
XIII				XIII			
XIV	485	5.0	4.35	XIV	365	12	10.44
XV	505	4.3	3.74	XV	380	11	9.57
600	600	2.3	2.0				
650	650	1.7	1.48				
700	700	1.3	1.133				
750	750	0.96	0.836				
800	800	0.73	0.635				

TABLE A.4 INITIAL GAMMA MEASUREMENTS, PROTECTED STATIONS, SHOT HAMILTON
Project 2.12b, NBS film badge technique.

NW Quadrant				NE Quadrant			
Station Number	Slant Range	Dose		Station Number	Slant Range	Dose	
	yd	r	rads		yd	r	rads
Tank 67	39.6	430	374				
APC 66	62.9	715	622				
Tank 65	70.1	300	261				
40 *	24.9	1,750	1,522	62 *	23.0	~1,800	~1,568
				58 *	27.3	1,050	914
				54 *	31.2	460	400
				55 *	30.6	420	366
				56 *	30.3	460	400
				49 *	36.8	230	200
				48 *	39.4	340	286
				47 *	41.2	290	252
				46 *	43.9	430	374
45 †	17.7	200 †	174 †	64 †	18.8	69	60
44 †	19.8	‡		63 †	21.3	‡	‡
38 †	26.4	60 †	52.2 †	61 †	24.4	130 †	116 †
43 †	21.3	900 †	783 †	59 †	24.9	680 †	592 †
41 †	22.9	1,100 †	957 †	60 †	24.5	590 †	505 †
42 †	24.0	640 †	567 †	57 †	28.4	‡	‡
39 †	27.3	‡		51 †	32.8	480 †	418 †
36 †	28.4	530 †	470 †	52 †	32.4	450 †	392 †
37 †	29.1	500 †	435 †	53 †	32.2	480 †	418 †
34 †	34.6	400 †	348 †	50 †	35.3	390 †	340 †
35 †	34.7	450 †	392 †				
32 †	43.5	230 †	200				
33 †	43.7	240 †	209				

* Open foxhole.

† Two-thirds-covered foxhole.

‡ Offset foxhole.

‡ Defective film badges.

† Uncorrected readings.

TABLE A.5 INITIAL GAMMA MEASUREMENTS, PROTECTED STATIONS, SHOT HAMILTON

Project 2.12b, NBS film badge.

SW Quadrant				SE Quadrant			
Station Number	Slant Range	Dose		Station Number	Slant Range	Dose	
		yd	r rads			yd	r rads
Tank 69	48.7	370	322	Tank 68	40.8	720	626
APC 71	82.0	390	340	Tank 70	58.4	500	435
14 *	22.9	~2,300	~2,000	26 *	25.6	1,800	1,568
10 *	26.4	§	§	22 *	28.7	710	618
5 *	34.8	160	139	23 *	29.4	410	357
6 *	34.6	240	209	21 *	28.3	§	§
4 *	39.0	300	261	19 *	32.4	220	191
3 *	43.5	430	383	20 *	32.9	680	592
2 *	57.8	280	244	18 *	36.7	570	496
1 *	57.7	290	252	17 *	41.1	350	304
16 ‡	18.7	70 ¶	61 ¶	30 ‡	19.8	68	58.4
11 ‡	26.3	54 ¶	47 ¶	27 ‡	22.8	16	13.9
15 ‡	21.2	§	§	31 ‡	17.6	§	§
13 †	23.9	530 ¶	461 ¶	29 †	22.4	750 ¶	653 ¶
12 †	24.7	590 ¶	514 ¶	28 †	21.3	900 ¶	783 ¶
7 †	31.3	400 ¶	348 ¶	24 †	26.4	530 ¶	461 ¶
8 †	30.8	460 ¶	400 ¶	25 †	26.9	470 ¶	409 ¶
9 †	30.3	420 ¶	366 ¶				

* Open foxhole.

† Two-thirds-covered foxhole.

‡ Offset foxhole.

§ Defective film badges.

¶ Uncorrected readings.

TABLE A.7 INITIAL GAMMA AND NEUTRON MEASUREMENTS,
SURFACE STATIONS, SHOT HUMBOLDT

Station Number	Slant Range	Gamma *	
		yd	r rads
10	13.0		
25	26.4	19,000	16,530
50	50.7	5,500	4,790
100	100	2,800	2,439
200	200	500	435
300	300	160	139.2
450	450	41	35.7
600	600	14	12.2
700	700	7.5	6.53
800	800	4.1	3.5

* Project 2.12b, NBS film badge.

† Project 2.12a, threshold detector.

TABLE A.8 INITIAL GAMMA AND NEUTRON MEASUREMENTS, FOXHOLES,
AND ARMORED PERSONNEL CARRIERS, SHOT HUMBOLDT

Station Number	Slant Range	Gamma †	
		yd	r rads
5S *	10.5	14,500	12,620
10N *	13.3	16,000	13,920
15S *	16.9	†	†
20N *	20.1	6,000	5,220
25S *	23.7	5,900	5,140
5N †	10.5	13,600	11,840
10S †	13.3	13,200	11,490
15N †	16.9	3,900	3,390
20S †	20.1	6,400	5,570
25N †	23.7	1,500	1,305

APC 66 Southeast Quadrant

Front	28.4	19,000	16,520
Middle	30.0	11,500	10,000
Middle	30.0	9,800	8,530
Rear	32.4	10,000	8,700

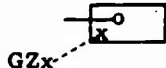
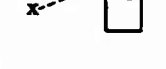
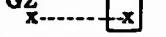
APC 70 Northeast Quadrant

Front	28.4	18,200	15,840
Middle	30.0	13,200	11,490
Middle	30.0	12,200	10,610
Rear	32.4	10,400	9,050

* Open foxhole. † Two-thirds-covered foxhole.
film badge. § Project 2.12a, threshold detector.

‡ Project 2.12b, NBS
¶ Film badge defective.

TABLE A.9 CALCULATED THEORETICAL DOSE IF ALL VEHICLES HAD BEEN AT 50-YARD DISTANCE, SHOT HAMILTON

Vehicle	Orientation	Exposure Quadrant	Actual Slant Range yd	Dose Corrected to 50- Yard Slant Range	
				gamma	r
M-48 Tank					
65		NW	70.1	588	
67		NW	39.6	271	
68		SE	40.8	480	
69		SW	48.7	350	
70		SE	58.4	685	
M-59 APC					
66		SW	62.9	1,130	
71		NW	82.0	1,050	

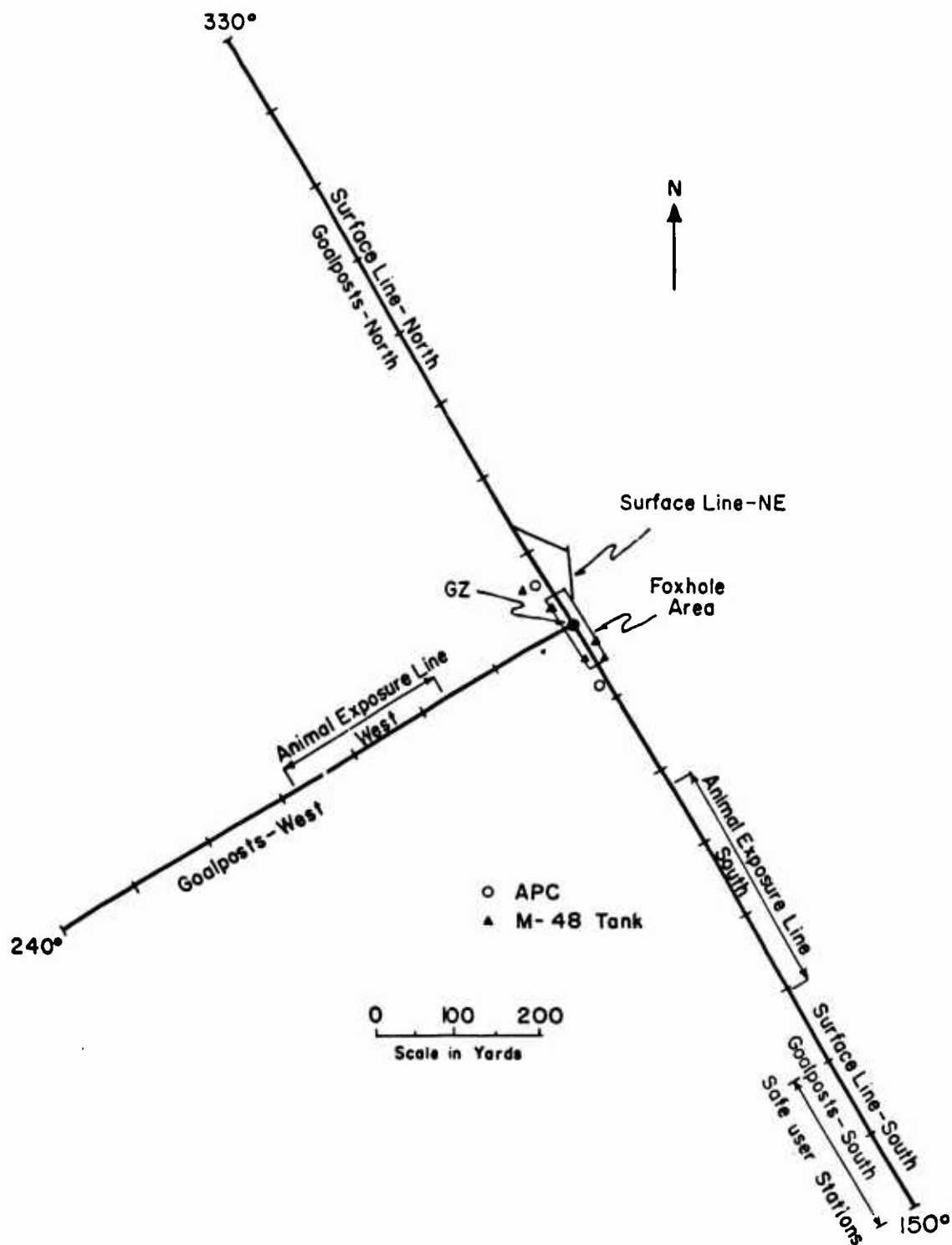


Figure A.1 Overall exposure array, Shot Hamilton.

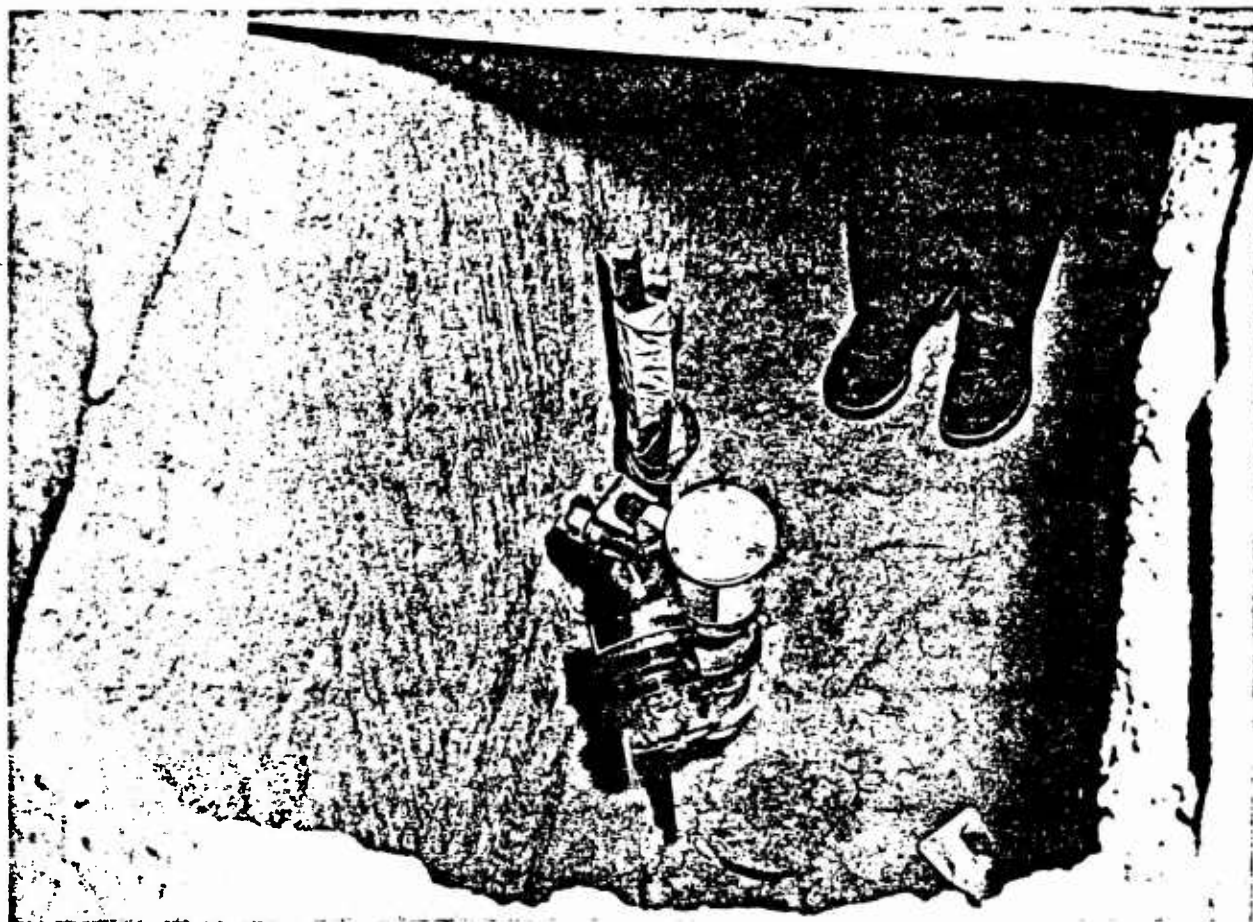


Figure A.2 Dosimetry in two-thirds-covered foxhole; Shot Hamilton.

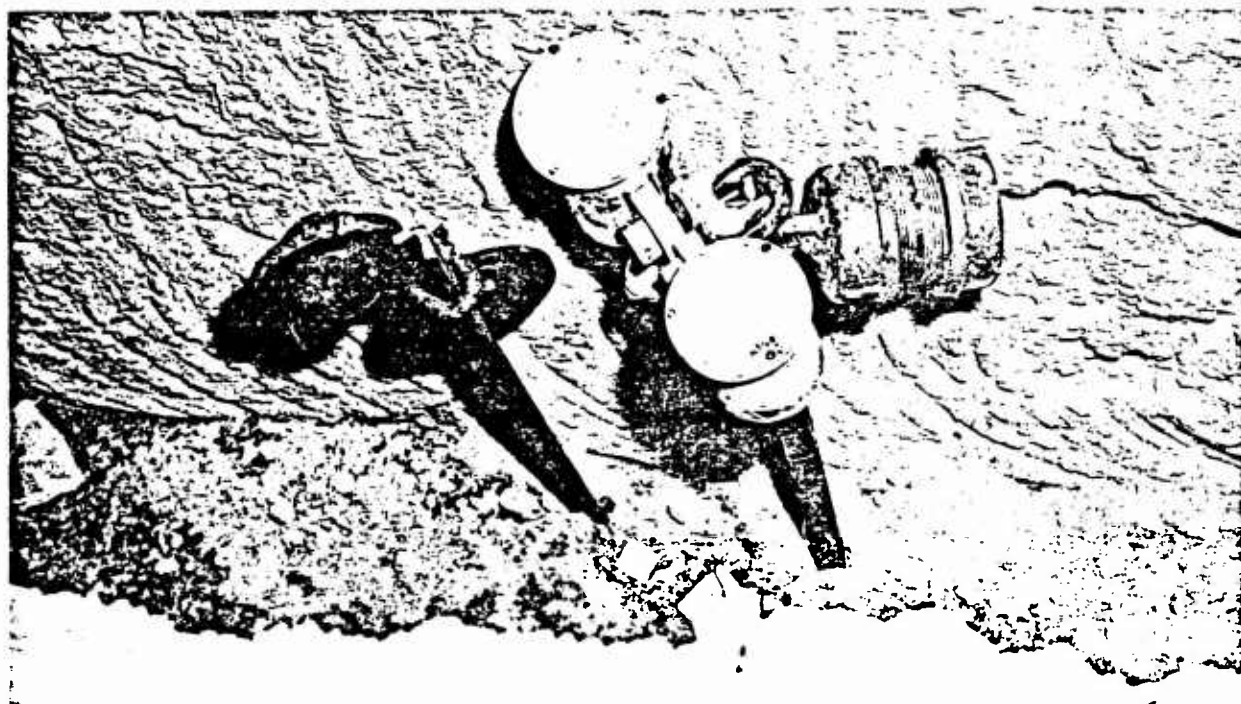


Figure A.3 Dosimetry in open foxhole; Shot Hamilton.



Figure A.4 Placing dosimetry adjacent to tank "driver"; Shot Hamilton.

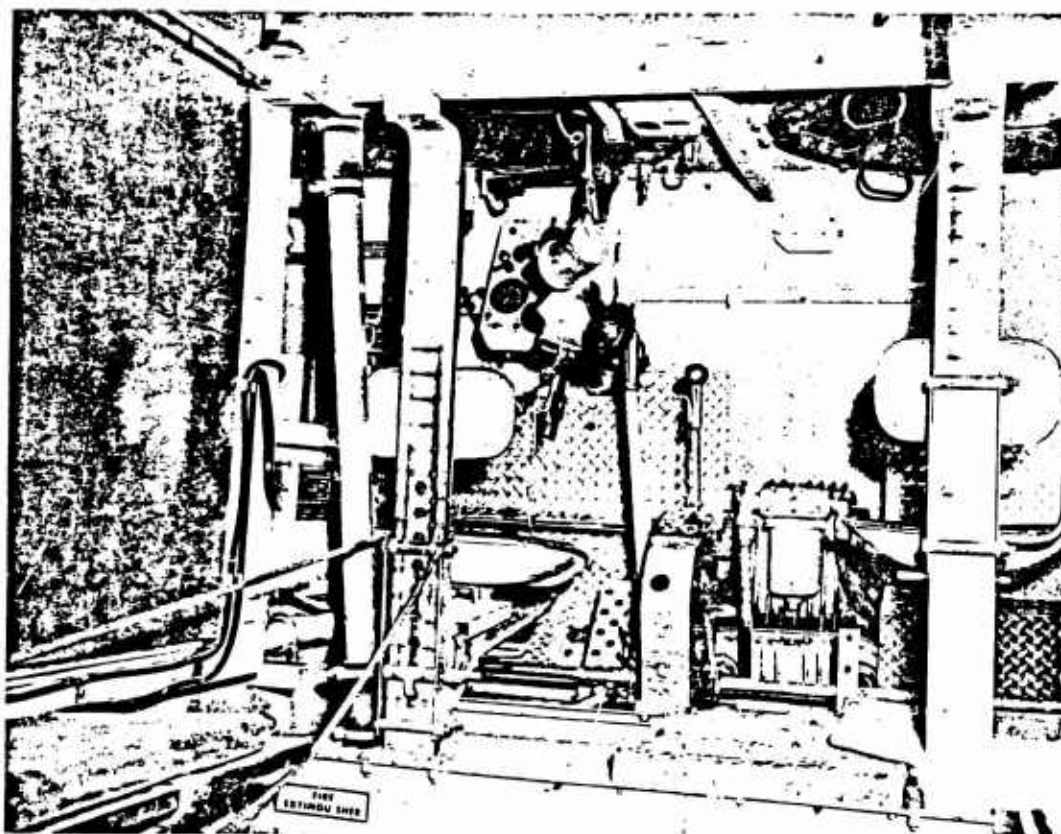


Figure A.5 Dosimetry adjacent to APC "driver"; Shot Hamilton.

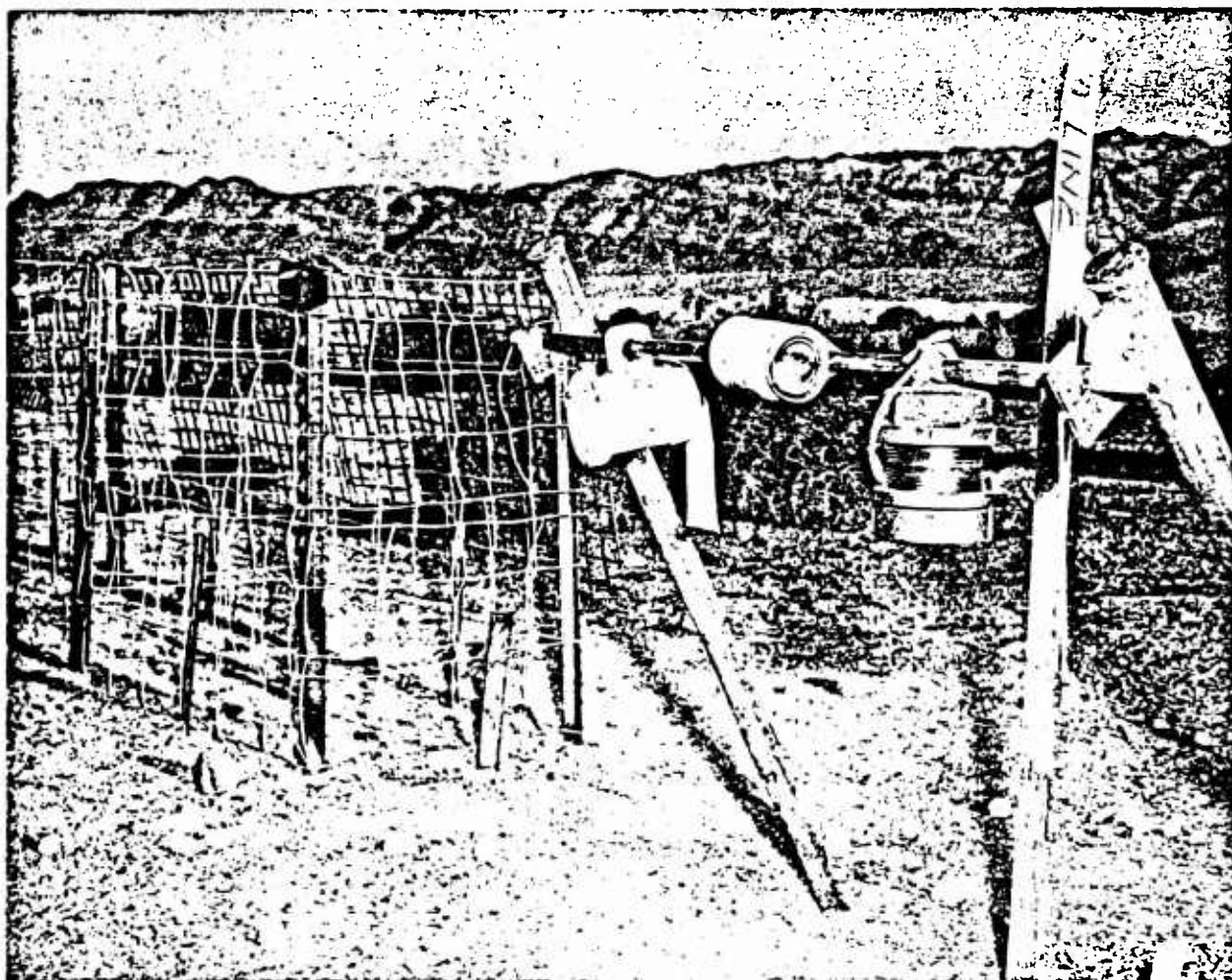


Figure A.6 Free-air dosimetry, gamma only, at "safe user" distance; Shot Hamilton.

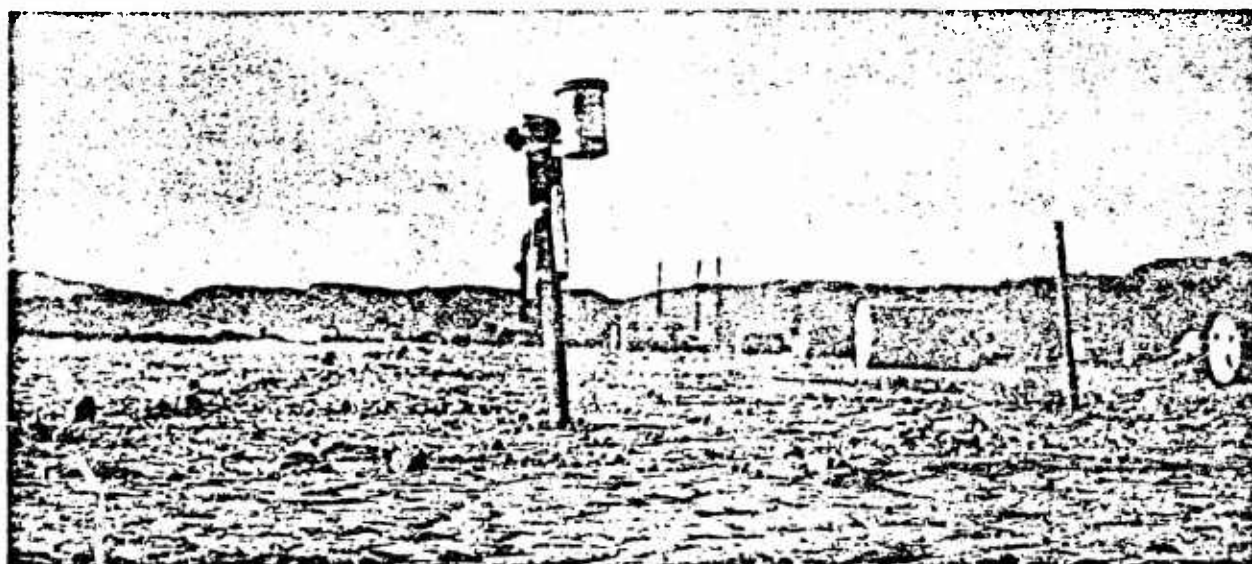


Figure A.7 Free-air dosimetry, gamma only.



Figure A.8 NBS film pack and blast shield.



Figure A.9 NBS film pack blast shield.

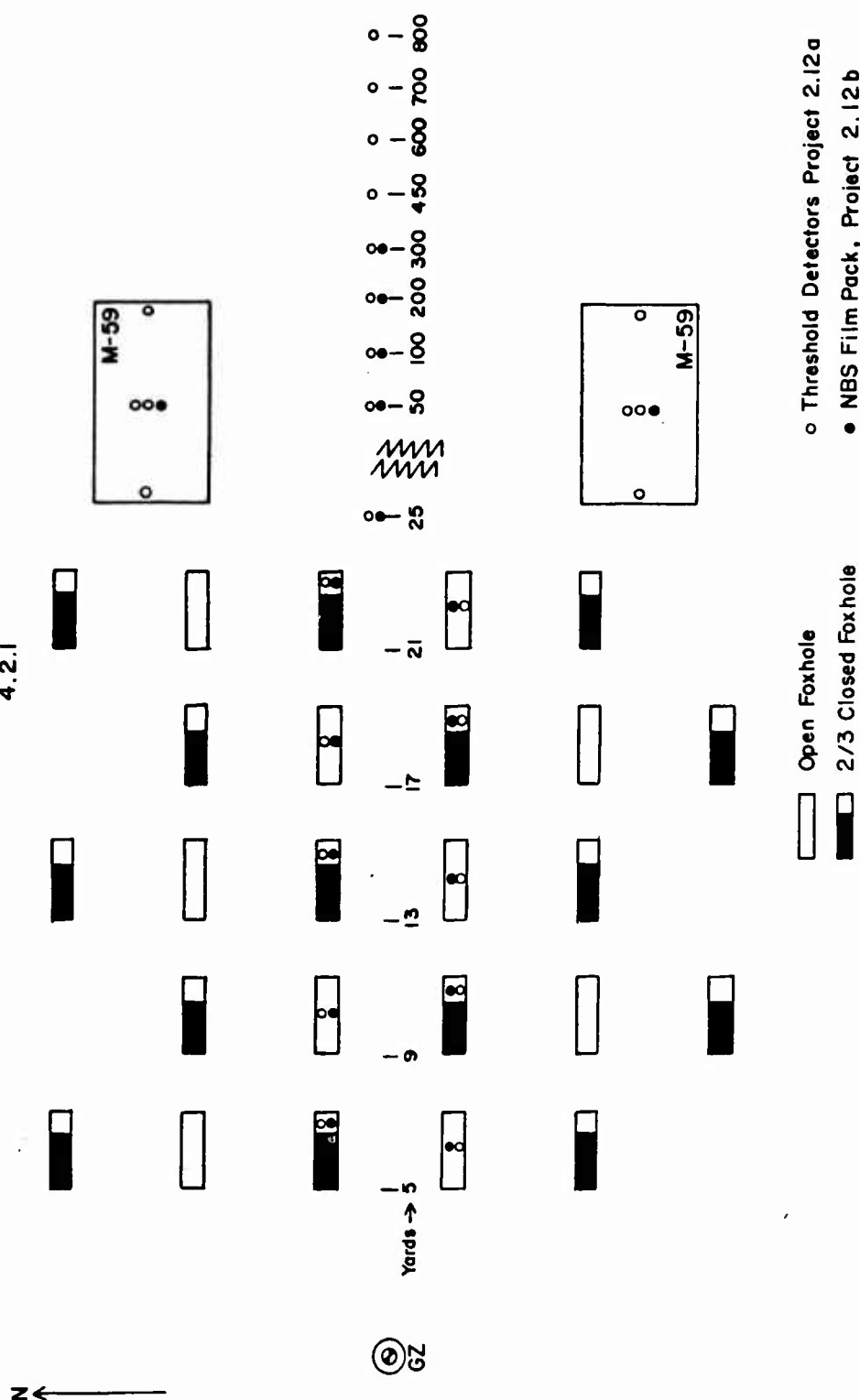


Figure A.10 Overall exposure array, Shot Humboldt.

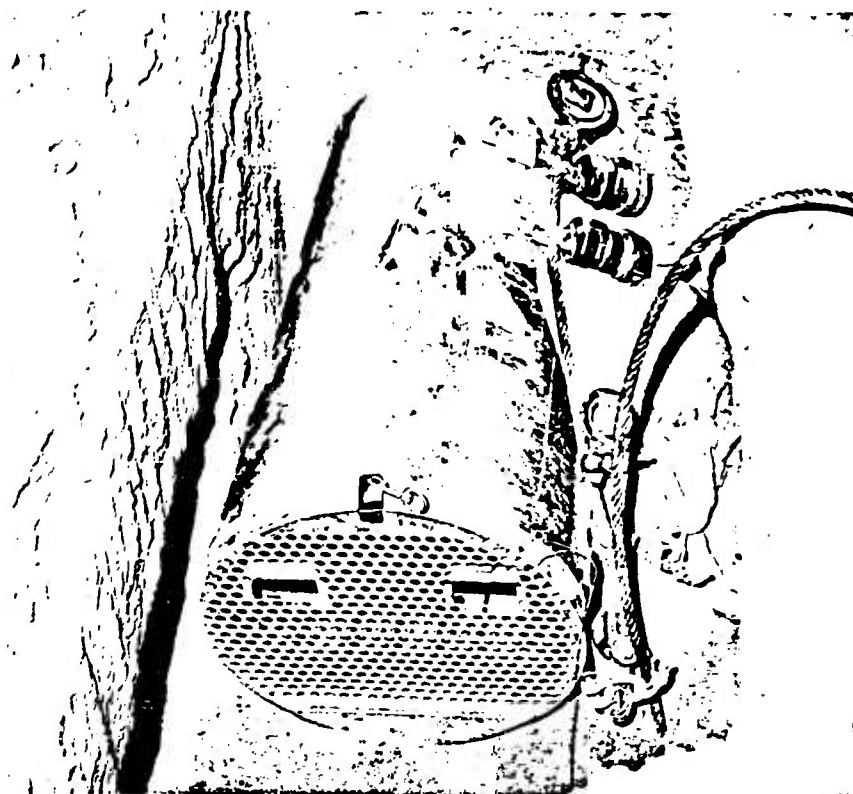


Figure A.11 Dosimetry in open foxhole, Shot Humboldt.

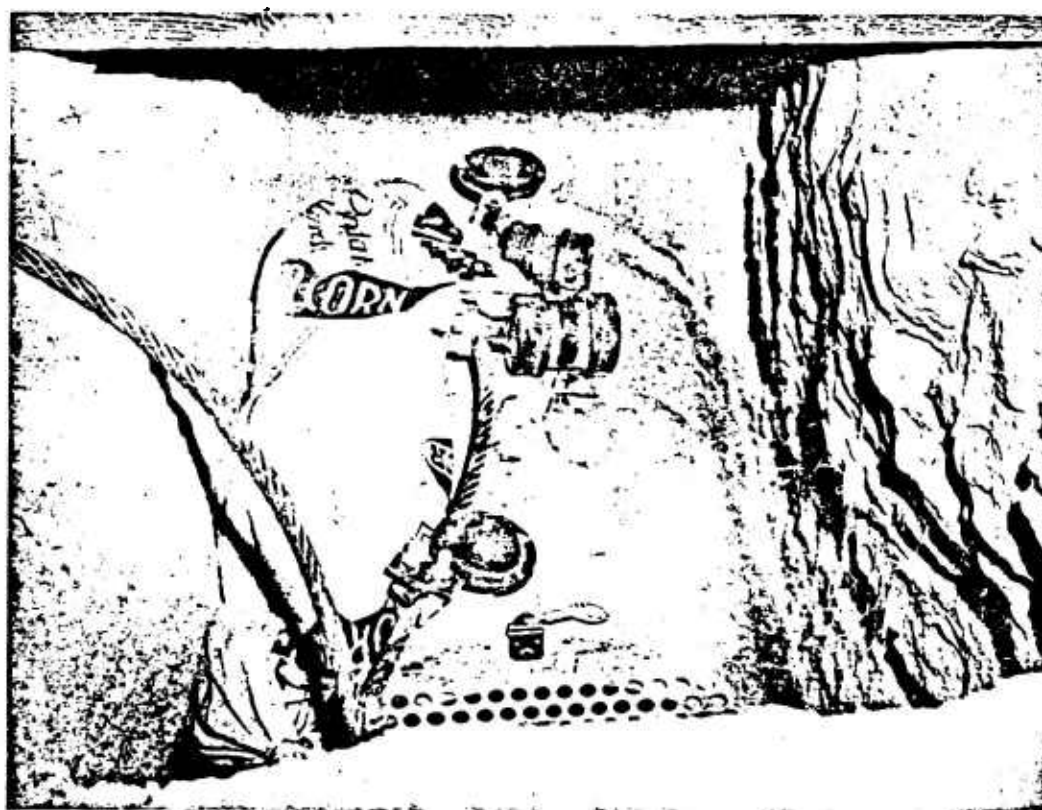


Figure A.12 Dosimetry in two-thirds-covered foxhole, Shot Humboldt.

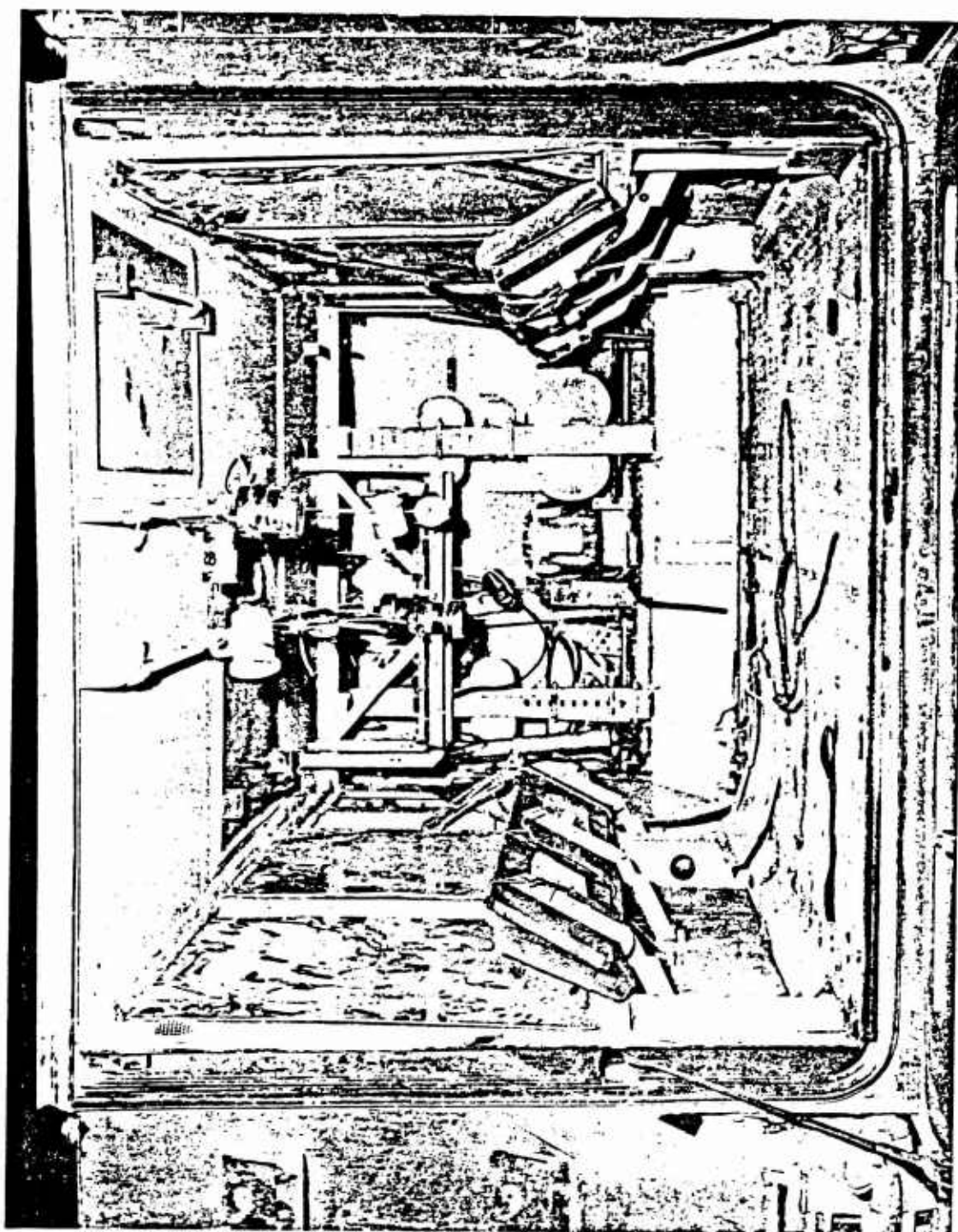


Figure A.13 Dosimetry in APC, Shot Humboldt.

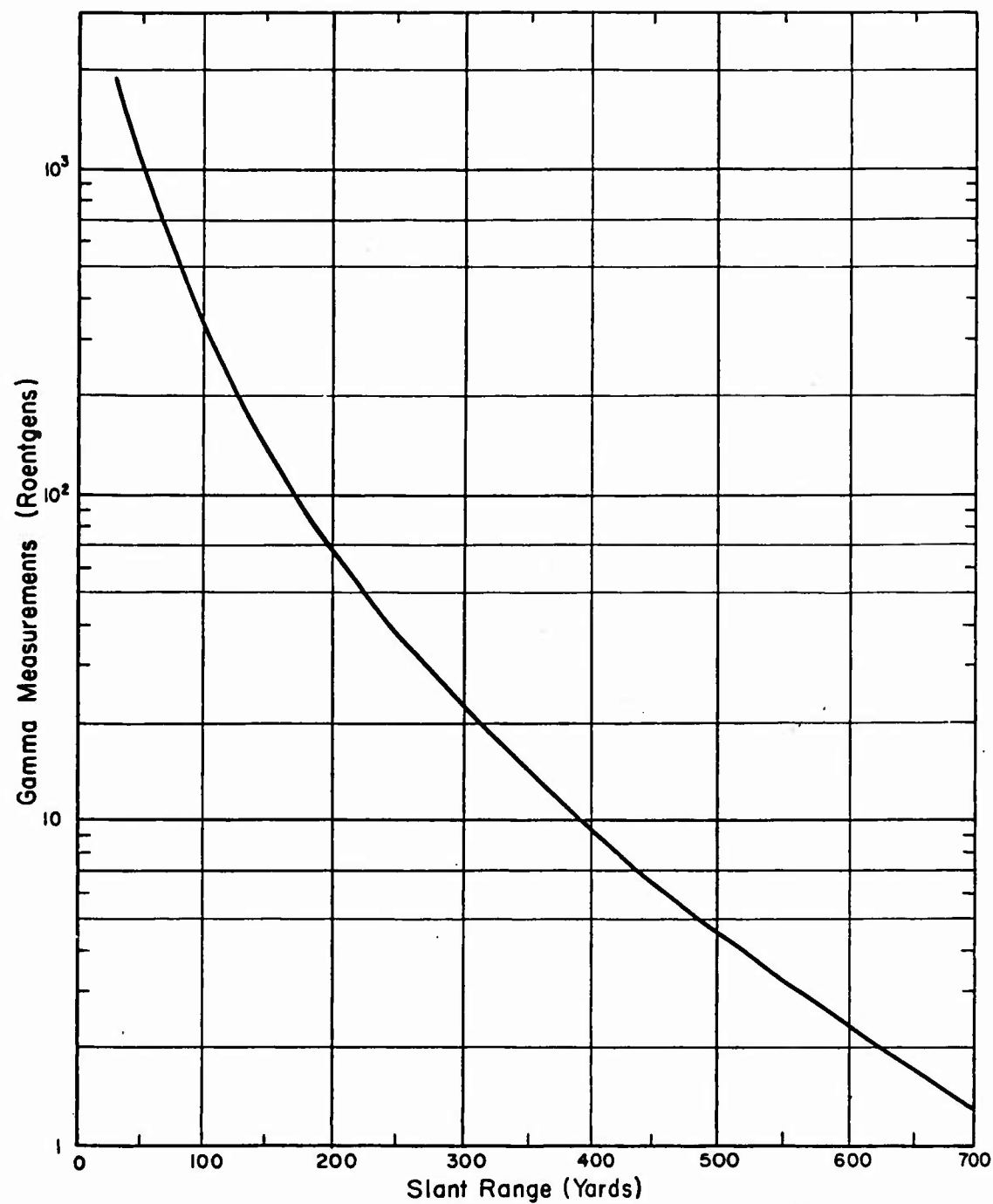


Figure A.14 Initial gamma measurements (surface)
versus slant range, Shot Hamilton.

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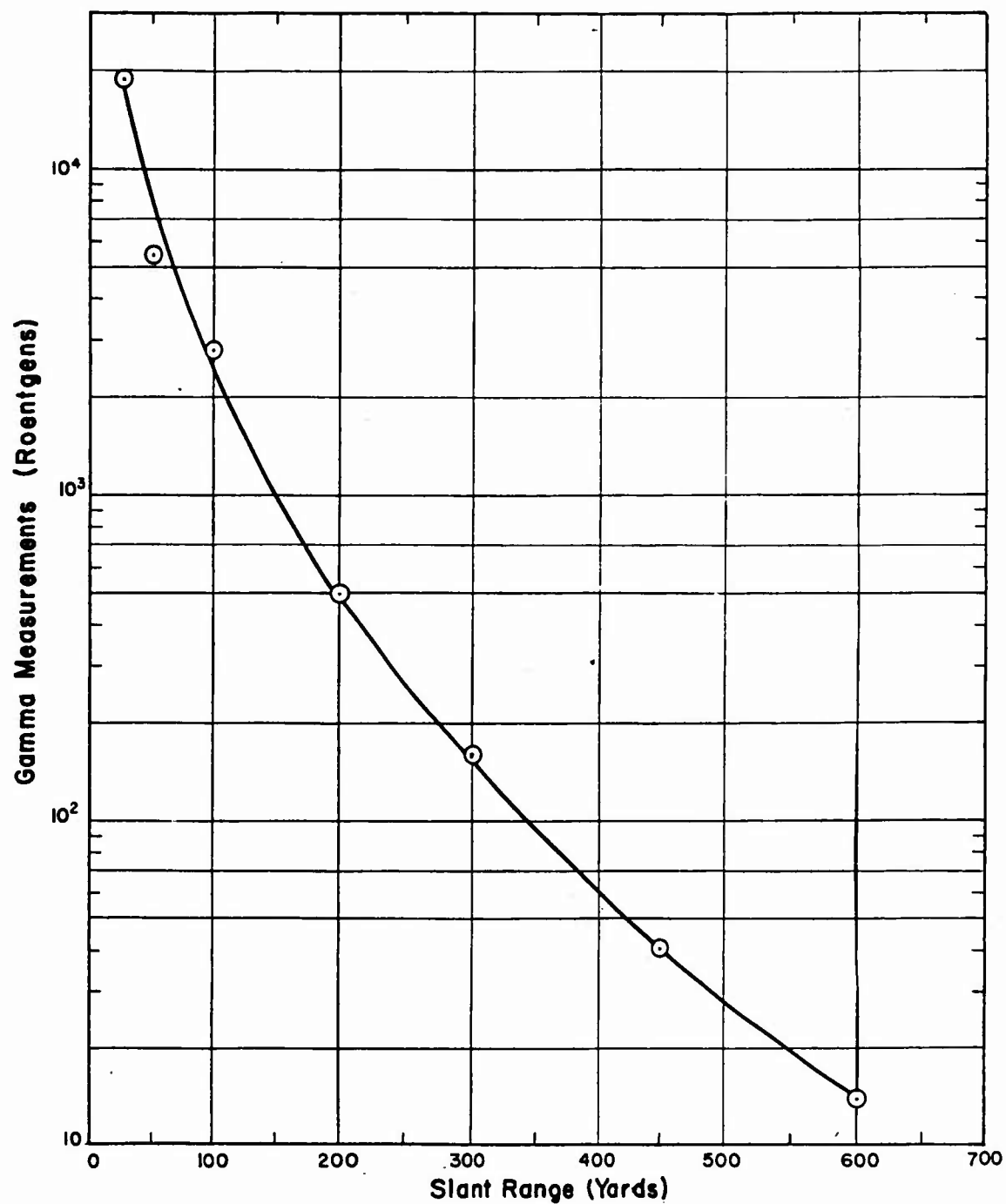


Figure A.16 Initial gamma measurements (surface) versus slant range, Shot Humboldt.

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Appendix B

NEUTRON-INDUCED Na^{24} ACTIVITY IN SWINE BLOOD

On 16 June 1958, a radiation accident occurred in the Y-12 plant at Oak Ridge, Tennessee. As a result of this accident, eight individuals were exposed to radiation in excess of established limits. The details of the accident are described in Reference 52.

In brief, the accident occurred because of the inadvertent introduction of a highly enriched uranium solution into a 55-gallon drum. Within this container the necessary conditions for criticality occurred; as a result, the individuals in the immediate vicinity received varying doses of whole-body mixed neutron and gamma radiation.

Various methods of physical dosimetry were utilized to estimate the neutron dose received by the exposed personnel, but these doses were so high and inconsistent with the early clinical course observed that they were disregarded. Instead, Na^{24} activity in the urine and blood was measured. Once the Na^{24} activity in the blood was established, a mockup experiment was done using a burro to establish the relationship between a known neutron dose and a measured level of Na^{24} activity in blood. On this basis, the neutron dose, in rads, absorbed by the humans exposed was calculated. The values so obtained (including methods for establishing gamma-neutron ratios) were in good agreement with the subsequent clinical course of the exposed people.

The encouraging results obtained at Oak Ridge led to the belief that Na^{24} induced activity might be practical as a field biological neutron dosimeter.

Swine exposed to Shot Hamilton were bled as soon as possible after the detonation. The specimens, 20- to 30-cm³ heparinized blood, were flown to WRAIR. The Na^{24} gamma activity of the blood was measured in the low-level whole-body counting facility. The dose absorbed was calculated as in Reference 52. The correlation between this dose and the various physical methods of neutron dosimetry utilized for Shot Hamilton was compared.

A Nuclear-Chicago Corporation well-counter and scaler was shipped to the NTS to determine whether counting by this relatively simple method was practical. Theoretical calculations indicated that the well-counter would be useful during the first two half-lives of Na^{24} (about 28 hours), but thereafter would be able to detect only very high initial activity.

Animals exposed to Shot Humboldt were utilized in the same manner as for Shot Hamilton. Random blood specimens were submitted to WRAIR for measurement and calculation of activity.

Twenty-two exposed swine were selected randomly and blood was sent to WRAIR, where counting was begun at $H + 28$ hours. In addition, six unexposed samples were sent. All activity values listed hereafter are corrected to H hour. Of the six control specimens submitted (personnel at WRAIR had no knowledge of the expected activity in the individual samples), three were reported as negative and three with doses of less than 5 rads. This was probably due to contamination of the bottle by active samples in the same container. The remaining 22 specimens had activity ranging from 1.2 to 142.2×10^{-6} $\mu\text{curie/cm}^3$ of whole blood corrected to H hours. These samples were counted several times in the next 24 to 72 hours, and the decay obtained was consistent with that for Na^{24} . In rads, the dose range is from 15 to 1,777. Tables B.1 and B.2 give the pertinent data and also indicate the dose as measured by various physical methods.

The well-counter at NTS could not be used for 24 hours after Shot Hamilton, because the radioactive cloud passed directly over NTS, raising the background to between 20 and 30 times normal. The random samples were counted on $D + 2$ days but were inactive. Even at this time, background was twice normal, which imposed severe limitations on the sensitivity of the equipment.

From Shot Humboldt, 22 samples from exposed swine from the APC's were flown to WRAIR. Table B.3 lists the pertinent estimated air measurements and Na^{24} values.

The neutron dose, as defined by induced Na^{24} activity in the blood of the swine exposed to Shot Hamilton does not agree with the preliminary values obtained by the fission-foil technique. In most cases the Na^{24} measurement indicates a dose twice that obtained by the foil system. The reasons and the implication of this awaits further study.

For Shot Humboldt, there is less correlation between incident dose to the animal and Na^{24} measured dose. Although the swine were tethered in the APC, their actual positions were not known with complete accuracy. Furthermore, in physical dosimetry, distances between points can be measured to only a certain degree. For this reason, the data in Table B.3 is presented with the physical measurements as only three distinct points.

The results obtained indicate that measurement of Na^{24} blood activity is a feasible procedure and will give a biological indication of dose. It will detect not only doses in the thousands of rads but is also sensitive to doses as low as 15 rads. When the neutron dose is lower than 2,000 rads, there is better correlation with physical methods of neutron dosimetry (Tables B.1 and B.2). When the dose is higher, the correlation is not as good. The reasons for this are not clear at present. From a clinical standpoint, however, wide variations as in the high dose range are probably academic.

Thus, for the first time a biological field dosimeter is available that is specific for neutron radiation and is measurable immediately after exposure. There are no false positives.

In terms of prompt radiation in which the neutron component may be quite large, this is a valuable step forward. The Na^{24} activity found in the blood must mean exposure of some degree, and it may then be possible to approximate the gamma dose delivered to the same individual.

A standard, well-type scintillation counter can detect as little as 5×10^{-4} microcurie of Na^{24} per milliliter in a total counting volume of 3 mls, with a standard error of not more than 5 percent and a counting time of 10 minutes. If the specimen is obtained within a few hours, this method can indicate neutron exposures as low as 18 rads. Obviously, higher activation levels require less counting time, but, if the counting is delayed more than one half-life (15 hours) then either the counting time must be doubled or the lowest exposure detected must be increased by a factor of two. These values indicate the usefulness of this procedure. If fallout had not occurred over NTS after Shot Hamilton, it would have been possible to prepare estimates of neutron exposure, within a few hours after the detonation.

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Appendix C

REPORT ON AIR SAMPLING FOR SHOT HAMILTON

This material was prepared by Harry S. Jordan, Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

The evaluation of the inhalation problem at a distance approximating the distance of weapon delivery was accomplished by air sampling at six downwind points on a 600-yard radius from ground zero (Figure C.1).

High efficiency glass-fiber filter papers in Staplex high volume air samplers were used for air sampling. The reported efficiency of this paper is 99.99 percent for 0.3-micron particles. The airflow rate for the various samplers, as determined by calibrated rotameters, ranged from 45 to 60 ft³/min.

The duration of air sampling was fixed by starting the samplers, with a signal from the control point, at H - 1 minute and stopping them after 21 minutes by means of an electrical timer.

The inhalation hazard at ground zero could result from the initial airborne plutonium and from plutonium initially deposited on the ground but resuspended by activities within the area.

Air samplers, Staplex units with filter, mounted on the cabs of the two pickup trucks participating in the initial reentry, were used to evaluate the initial airborne concentration of plutonium near ground zero. Vehicle 8 approached ground zero on the south exposure axis, and Vehicle 10 approached on the north exposure axis (Figure C.2).

Sampling was initiated at a point 300 yards from ground zero. Both trucks penetrated to within 30 yards of ground zero. Sampling was discontinued when the trucks passed the 300-yard point on withdrawal. The reentry was accomplished at H + 12 minutes, and sampling was accomplished from about H + 15 to H + 30 minutes (Table C.1). The actual time for sampling was determined by means of an electrical timer in each case.

In order to determine the difference in airborne contamination before and after vehicle activity around ground zero, sampling was accomplished at H + 2 hours, prior to and during a recovery operation. Two pickup trucks, each with two Staplex air sampling units mounted on the cab roof, penetrated to the 3-r line, approximately 30 yards from ground zero. One vehicle (LASL 1) entered on the south axis, and the other vehicle (LASL 3) entered on the north axis. A 5-minute sample was obtained at the 3-r line (Table C.2).

Air sampling for resuspended matter was accomplished by having pickup trucks, with samplers mounted on the cab roof, follow immediately at the rear of a 2½-ton 6 × 6 cargo truck used on a recovery mission at H + 2 hours. The trucks used for sampling penetrated to the 3-r line (Table C.3).

Resuspension studies were also made within 30 to 35 yards of ground zero on D - 5 days and D + 4 days (Table C.4). For these studies, four air samplers were mounted 30 inches above the ground and arranged in a line approximately 30 yards in length. A vehicle about 15 yards upwind from the samplers was used to churn the dust from the ground. The resulting dust cloud from such activity is considered to represent a maximum resuspension of material deposited on the ground.

As a matter of interest, readings were taken at the 3-r line around ground zero at H + 2 hours, with portable alpha monitoring instruments (Figure C.3).

Also, because a relatively large amount of beryllium was in place near the device, the airborne material collected on the filter papers was analyzed for beryllium. There was no beryllium detected, the limits of detection approximating 0.1 µg/m³.

The concentration of airborne plutonium 300 yards downwind from ground zero (Figure C.1) is listed in Table C.5.

All counting of filter paper for alpha activity was accomplished a minimum of 5 days after collection to allow for the decay of natural radioactive airborne particles. Counting was accomplished by a gas flow proportional counter with a large 10-by-7 probe. The counter was adjusted and checked to prevent the counting of beta particles.

The results obtained downwind, at a point approximating the weapon delivery distance, indicated that airborne contamination would not be a problem at that point. Admittedly, this is but one test under certain conditions, but the weather and wind conditions at the time of the test were such as to give reasonable assurance that the maximum concentration that could be expected at that distance would not exceed the test results by more than a factor of 10.

The concentration of airborne plutonium at ground zero as indicated by the air sampling is contrary to

expectation, because the concentration increased rather than decreased with elapsed time. It is believed that the data resulted from the fact that the plutonium was implanted in the wooden members of the platform, and this would continued to burn for some time after the detonation. It is not possible to extrapolate the data, but it would appear reasonable to presume that the concentration of plutonium in the initial cloud would be considerably higher than the reported levels.

The resuspension studies, before the shot, indicated that little, if any, of the alpha activity in the dust cloud could be attributed to material resuspended from ground zero by the blast effect of the device.

The resuspension studies after the shot indicated that a hazard could exist to personnel required to engage in activities around ground zero, in which appreciable dust is resuspended. The readings of the alpha-survey meter cannot be used to correlate the ground concentration with the concentration of resuspended activity, because the ground concentration in many cases exceeded the upper scale of the survey instrument. In addition, a considerable portion of the activity on the ground was contained in small splinters of charred wood.

The alpha readings did not indicate any general fallout pattern. This is due to the inability to read alpha contamination on different surfaces with the same efficiency and to the fact that the contamination at many places was due to blown debris rather than fallout. Considerable fallout of alpha activity is indicated by the fact that horizontal surfaces of equipment, such as tanks, were highly contaminated (in excess of 20,000 counts/min for each instrument probe) whereas the sides of the equipment were not contaminated.

TABLE C.1 CONCENTRATION OF AIRBORNE PLUTONIUM, INITIAL CLOUD AT H + 15 MINUTES, SHOT HAMILTON

Vehicle	Concentration (dis/min)/m ³
DOD 8	660
DOD 10	535

TABLE C.2 CONCENTRATION OF AIRBORNE PLUTONIUM AT 3-r LINE AT H + 2 HOURS, SHOT HAMILTON

Vehicle	Air Sampler	Concentration (dis/min)/m ³
LASL 1	A	2,420
	B	2,440
LASL 3	A	1,030
	B	1,080

TABLE C.3 CONCENTRATION OF AIRBORNE PLUTONIUM, RESUSPENDED AND AIRBORNE, SHOT HAMILTON

Vehicle	Air Sampler	Concentration (dis/min)/m ³
LASL 2	A	1,920
	B	2,389
LASL 4	A	919
	B	710

TABLE C.4 CONCENTRATION OF AIRBORNE ALPHA EMITTING MATERIAL RESUSPENDED, D - 5 AND D + 4 DAYS

Sampler		Concentration (dis/min)/m ³
D - 5	1	3
	2	15
	3	7
	4	4
D + 4	1	1,221
	2	935
	3	1,344
	4	701

TABLE C.5 CONCENTRATION OF AIRBORNE PLUTONIUM AT WEAPON DELIVERY DISTANCE

Station	Concentration (dis of Pu/min)/(m ³ of air)
531.01	15
531.02	68
531.03	61
531.04	10
531.05	6
531.06	1

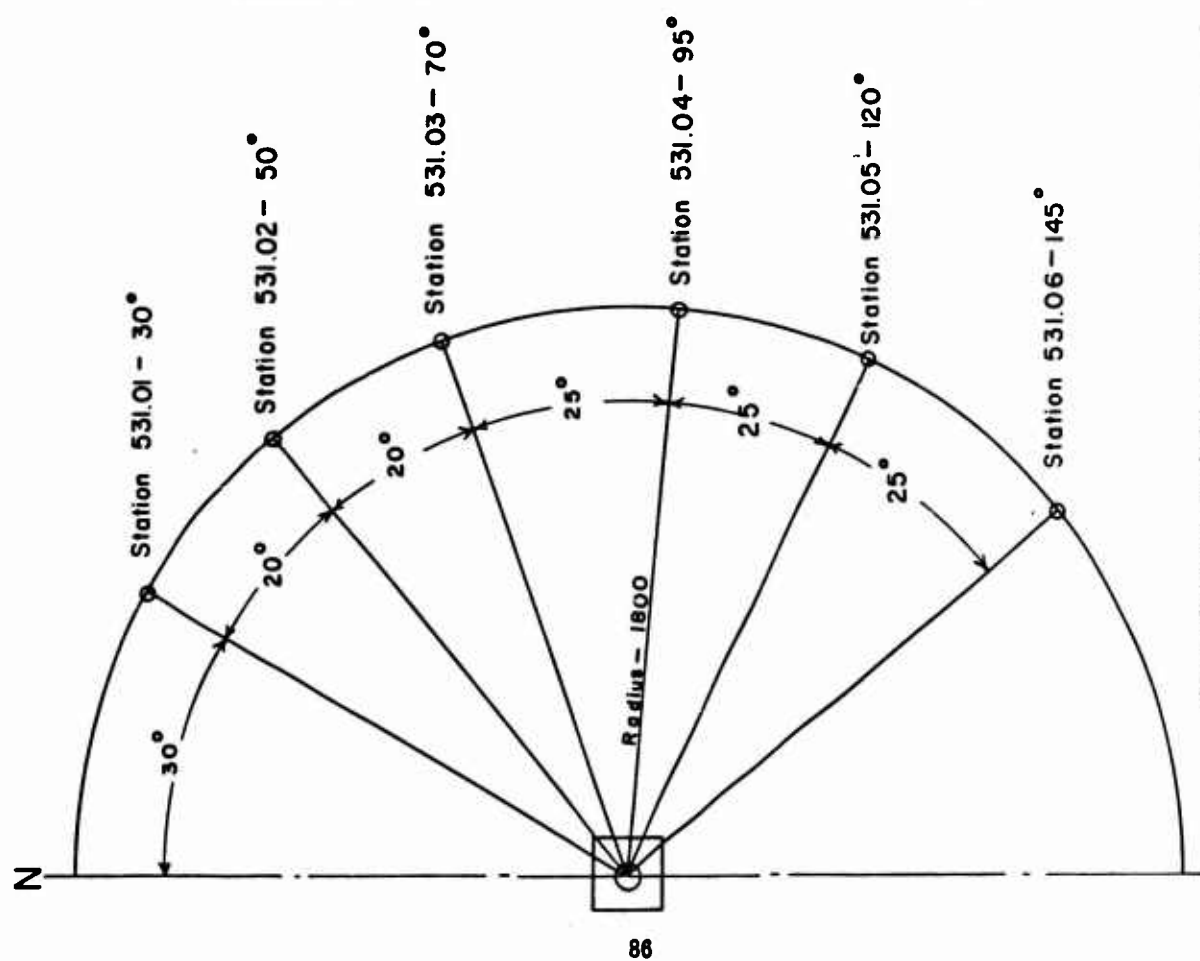


Figure C.1 Downwind alpha sampling stations; Shot Hamilton.

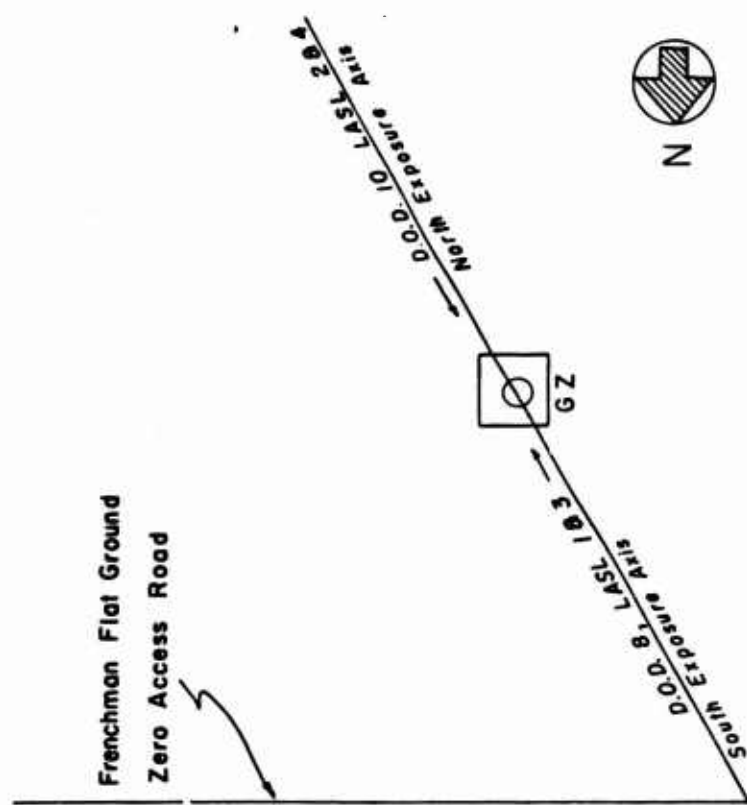


Figure C.2 Route of vehicles with air samplers; Shot Hamilton.

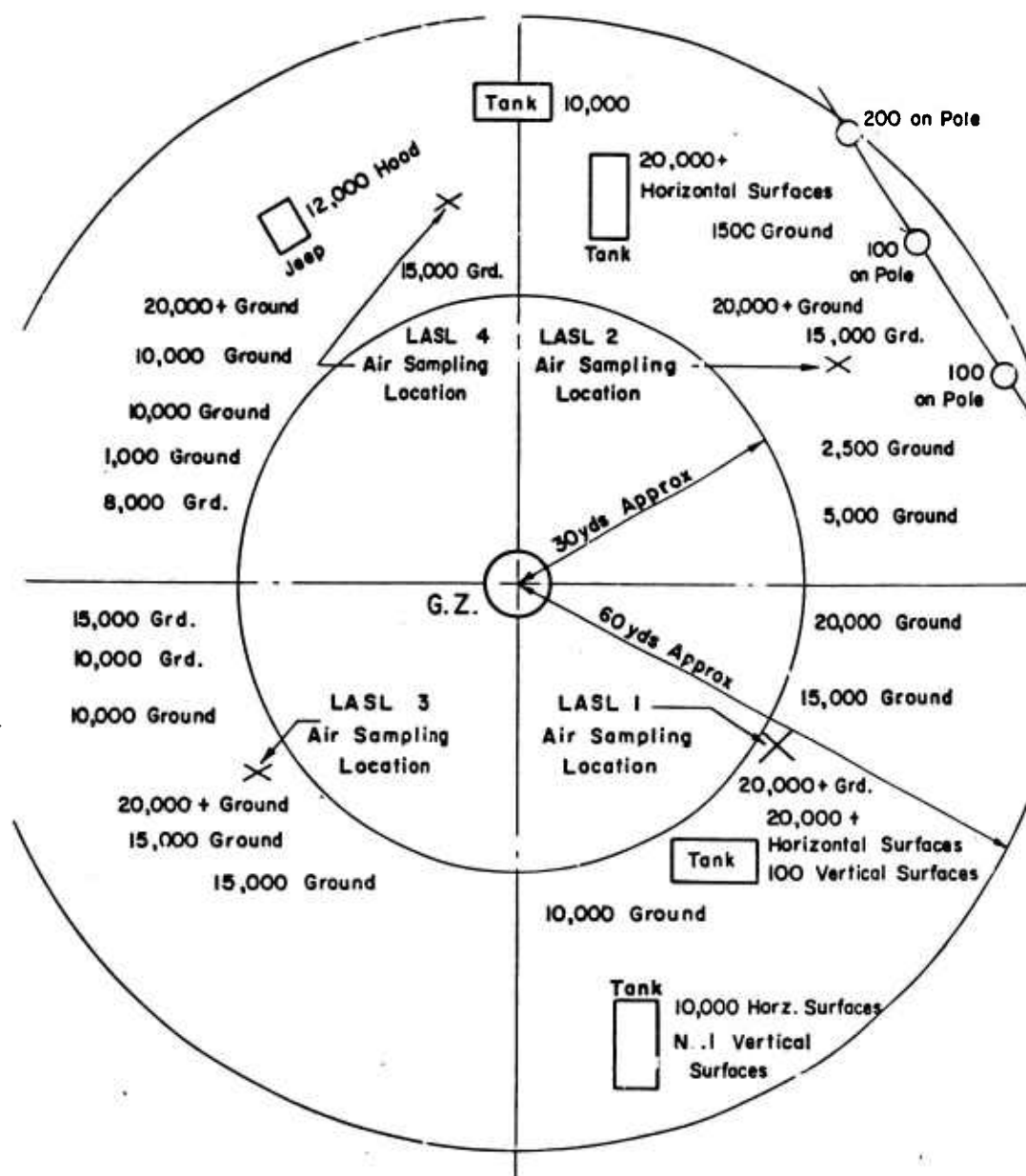


Figure C.3 Portable alpha survey meter readings; Shot Hamilton.

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