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OPERATION PLUMBBOB

Program 2

NEUTRON AND GAMMA RADIATION FROM SHOT LAPLACE

Nevada Test Site
May-October 1957

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

November 20, 1959

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The objectives of this experiment were to determine, for Shot Laplace, a 1.22-kt device fired late in Operation Plumbbob: (1) intensity and decay of the neutron-induced gamma field; (2) neutron flux and spectra as a function of distance; (3) neutron flux as a function of soil depth with certain selected detectors; and (4) neutron dose and initial gamma dose as a function of distance. Keywords: Nuclear explosion testing; NTPR (Nuclear Test Personnel Review); and Nevada Test Site.

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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.

This report has been reproduced directly from available copies of the original material. The locations from which material has been deleted is generally obvious by the spacings and "holes" in the text. Thus the context of the material deleted is identified to assist the reader in the determination of whether the deleted information is germane to his study.

It is the belief of the individuals who have participated in preparing this report by deleting the classified material and of the Defense Nuclear Agency that the report accurately portrays the contents of the original and that the deleted material is of little or no significance to studies into the amounts or types of radiation received by any individuals during the atmospheric nuclear test program.

FOREWORD

This report presents the final results of one of the 46 projects comprising the military-effect program of Operation Plumbbob, which included 24 test detonations at the Nevada Test Site in 1957.

For overall Plumbbob military-effects information, the reader is referred to the "Summary Report of the Director, DOD Test Group (Programs 1–9)," ITR–1445, which includes: (1) a description of each detonation, including yield, zero-point location and environment, type of device, ambient atmospheric conditions, etc.; (2) a discussion of project results; (3) a summary of the objectives and results of each project; and (4) a listing of project reports for the military-effect program.

ABSTRACT

The objectives of this experiment were to determine for Shot Laplace, a 1.22-kt device fired late in Operation Plumbbob: (1) intensity and decay of the neutron-induced gamma field; (2) neutron flux and spectra as a function of distance; (3) neutron flux as a function of soil depth with certain selected detectors; and (4) neutron dose and initial gamma dose as a function of distance.

The documentation of the induced field intensity and its decay was accomplished through use of two types of gamma survey meters, the AN/PDR-T1B and the Jordan Model AGB-10SR. Neutron flux and spectra were measured by the threshold-detector technique, employing gold, cadmium-shielded gold, plutonium, neptunium, uranium, and sulfur for ground-surface measurements, and gold, cadmium-shielded gold, and sulfur for soil-depth measurements. Various types of film-badge and chemical dosimeters were used to measure the initial gamma dose, while neutron dose was determined by calculation from the flux-spectra results.

The neutron-induced gamma radiation field and its decay from H + 1 to H + 36 hours was successfully documented. The observed decay rate indicated Na^{24} and Mn^{56} as being the major contributing radionuclides during the time covered by the observations. A survey of the neutron-induced field at H + 27 hours indicated dose-rate levels ranging from 2.6 r/hr at a slant range of 320 yards to 1.38 mr/hr at 2,015 yards. When extrapolated back to H + 1 hour, the 320-yard reading was found to be equivalent to 16.4 r/hr.

The data obtained in the documentation of thermal (gold) and fast (sulfur) neutron fluxes with soil depth confirmed earlier observations that thermal flux peaks at a depth of approximately 4 inches, whereas the high-energy flux degrades rapidly with depth.

Neutron irradiation of elemental samples of sodium, chromium, and manganese produced the induced activities of Na^{24}, Cr^{51}, and Mn^{56}. The specific activation was reasonably well related to the cross sections of the reactions involved.

The measured neutron dose exceeded that predicted by TM 23-200 by an average factor of 2.6 for ranges between 300 and 700 yards. Although this is within the prediction-method reliability factor of 4 quoted for weapons of this type, the Laplace data is con-

sidered representative of prediction techniques as they apply to devices and should be used to improve the weapons.

The initial gamma dose data showed that Laplace produced a greater-than-predicted gamma dose at all ranges, with the greatest discrepancy occurring at the close-in ranges. The effective mean free path of the initial gamma radiation at ranges in excess of 1,500 yards was 440 yards, slightly greater than the value predicted (using a relative air density of 0.8) of 425 yards.

PREFACE

The information contained in this report represents the results of a combined effort involving a number of participating agencies. The experiment was conceived, designed, and administered by Program 2, with practically all of the instrumentation, field work, and data reduction being accomplished by groups from both DOD-project and non-project organizations. Although the data obtained by DOD-sponsored projects appears in the reports pertaining to their basic efforts, that obtained by the program and non-project participants would not normally be reported. It is, therefore, the primary purpose of this report to present this latter information and, secondarily, to give a comprehensive picture of all results obtained.

The successful execution of this experiment was due to the wholehearted cooperation of many agencies. Although it is not possible to personally cite the many individuals concerned, the authors do wish to specifically acknowledge the contributions of Project 2.2, Naval Radiological Defense Laboartory, C.S. Cook, Project Officer; Project 2.3, Chemical Warfare Laboratory, D. L. Rigotti, Project Officer; Project 2.10, Air Force Special Weapons Center, Captain E.N. York, Project Officer; Lexington Signal Depot, C. Slover; USAF School of Aviation Medicine, S. Sigoloff; and Edgerton, Germeshausen, and Grier, Inc.

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INTRODUCTION

1.1 OBJECTIVES

The objectives of this experiment were to determine for Shot Laplace, a 1.22-kt detonation which occurred late in Operation Plumbbob: (1) intensity and decay of the neutron-induced gamma field; (2) neutron flux and spectra as a function of distance; (3) neutron flux as a function of soil depth with certain selected detectors; and (4) neutron dose and initial gamma dose as a function of distance.

1.2 BACKGROUND

Shot Laplace, was originally included in the early schedules of Operation Plumbbob.

Shot Laplace could be expected to produce a high neutron flux per unit yield. In consideration of this fact, the shot had been originally selected as that on which a DOD study of neutron-induced gamma activity in soils would be performed. Prior to the commencement of the operation, Shot Laplace was deleted from the schedule, and the induced activity study was transferred to Shot Owens. Following the completion of the soil study on Shot Owens, Shot Laplace was again rescheduled. Although most of the projects that had participated in the induced activity study had departed the test site by this time, it was decided that an effort should be made to document Shot Laplace insofar as possible. Of particular importance was the documentation of the decay of the resultant neutron-induced residual field, since the attempts to document the Shot Owens residual field decay had met with limited success. During Owens, no reliable measurements of the resultant induced gamma field were obtained for times earlier than H+40 hours (Reference 1). Shot Laplace also afforded an excellent opportunity for obtaining gross induced field data for Area 7 of the Nevada Test Site (NTS), the site from which the soil samples used earlier by Project 2.1 in their induced activity studies on Owens had been obtained. As originally planned, the induced soil activity experiment was to have been carried out on Shot Laplace in Area 7, and soil samples from this area were collected and prepared. The cancellation of Laplace prior to the operation, however, necessitated moving the experiment to Area 9, where Shot Owens was scheduled. This change in location occurred at such a late time as to preclude the preparation of a new set of soil samples. As a result, Area 7 samples were exposed in Area 9 on the assumption that the soils of these areas were basically similar. Since it was an objective of Project 2.1 to obtain empirical factors for correlating the activity induced in small soil samples with that generated in a large soil field, the possible differences between the soils of Areas 7 and 9 was a matter of some concern. The reinstatement of Shot Laplace was therefore welcomed, as it provided an opportunity to document an Area 7 induced field.

To provide a complete documentation of the field, it was considered necessary not only to measure the extent of the induced region and its decay, but also the nature and intensity of the neutron flux which generated it. This information would be required in any attempt to correlate the activity induced in the small samples by Shot Owens with that observed in the large field produced by Laplace. These measurements of neutron flux and spectra also permitted calculation of neutron dose as a function of distance, which was of interest as the Laplace device represented a candidate weapon.

For more complete definition of the neutron-induced soil-activity phenomena, neutron flux in the essentially thermal (< 0.3 ev) and fast (3 Mev) energy regions was also measured as a function of soil depth. Although similar measurements had been made during Shot Owens, specific information applicable to the Laplace situation was deemed essential. As little additional work was involved, this effort was extended to include measurement of activity in elemental samples of some materials that were possible contributors to induced soil fields.

The documentation of initial gamma dose as a function of distance was of particular interest to the Air Force.

For this reason, documentation of initial gamma dose as a function of distance was included in the overall experiment.

1.3 THEORY

In weapons detonated at a height above the ground of sufficient magnitude to preclude direct contact of the soil or ground environment with the resultant fission-product residue, local fallout will not occur. However, a neutron-induced residual field may be produced by interaction of neutrons from the detonation with soil elements, and this radiation field can be of concern in military operations.

In the fission process, not all the neutrons produced are needed to further the reaction; hence, a certain portion of the neutrons released are available to the surrounding medium. Some of these available neutrons are captured by the bomb components, while others escape to the external environment. The fraction that escapes is a function of weapon design.
are expected to permit large numbers of neutrons to escape. These neutrons are then scattered or captured in $N^{14}(n, \gamma)N^{15}$ reactions in the air or if they reach the ground surface, can be captured by various soil elements. This latter situation can and does result in the production of gamma-emitting radionuclides. In the event that relatively few radionuclides are produced, the identity and relative concentration of the primary contributors to the radiation field can be determined from an analysis of the decay and intensity of the resultant field. Previous experiments (References 2, 3, and 4) have indicated that, for NTS soil, the primary contributors to the induced gamma field are Al^{28} (2.3 m), Mn^{56} (2.58 h), and Na^{24} (15.0 h). The distribution of these activities in the soil depends on many parameters, including the variation of the neutron flux and spectra with depth and the physical and chemical characteristics of the soil. A more-complete discussion of induced-activity phenomena is given in References 1 and 5.

As a minimum, documentation of an induced field should therefore include measurement of (1) the intensity and decay of the field and (2) the neutron flux-spectra as a function of distance and soil depth. This experiment was designed to provide these basic measurements within the limits of capability existing in Program 2 at the time of the shot.

The measurement of neutron dose versus distance involved little additional effort, since dose data could be determined from the flux-spectra measurements made in support of the induced-activity study. The information, however, was particularly valuable because data on neutron dose versus distance was very limited. Such data is important in determining the neutron dose radii

Although measurements of gamma dose rate versus time were recognized as being particularly desirable in any evaluation of the gamma dose received by a delivery aircraft along its flight path, such measurements were not feasible within the severely limited capability that existed at the time. Integrated gamma dose could be measured relatively easily through use of film and chemical type dosimeters; thus, such measurements were included. Although it was not possible to directly evaluate the contribution of the various components of the initial gamma radiation pulse—alpha phase, peak to 1 msec, nitrogen capture, and fission-product gamma rays (see Reference 6)—from the total gamma dose measurements, it was expected that resolution of this type, if desired, could be made through application of the gamma time history data obtained by Plumbbob Projects 2.5 and 2.10 (References 7 and 8). It was recognized that the integrated dose would include the contribution of the residual field up to the time of dosimeter recovery; however, this was considered relatively unimportant, in that it would probably represent a small fraction of the total measured dose.

Chapter 2
PROCEDURE

2.1 SHOT PARTICIPATION

The reported experiment was conducted on Shot Laplace. The following information is pertinent to this nuclear detonation:

DEVICE:	LOCATION: Area 7, NTS
YIELD: 1.22 ± 0.05 kt	TEMPERATURE: 13.5 C
SUPPORT: Balloon	HUMIDITY: 35 pct
HEIGHT OF BURST: 750 feet	PRESSURE: 880 mb
DATE/TIME: 8 September 1957, 0559 PDT	RELATIVE AIR DENSITY: 0.84

2.2 INSTRUMENTATION

2.2.1 Description. Induced activity was measured with the AN/PDR-T1B (Signal Corps Radiac Training Set) and the Jordan Meter, Model AGB-10SR, a commercially available ionization chamber. The T1B has an accuracy variously quoted as ± 15 to 20 percent. Jordan Electronics, Inc., the manufacturer of the AGB-10SR instrument, maintains that the chamber is energy independent from 80 kev to 1.3 Mev, and that this energy independence is within 10 percent at 2.8 Mev. Field intensity was measured with a specially-prepared mounting jig that held both survey meters in fixed positions 3 feet above the ground. In this way it was assured that meter altitudes and field geometries were constant for all measurements.

Neutron flux and spectra were measured by means of threshold detectors furnished by Project 2.3. Each detector station consisted of the following detector elements: gold, cadmium-shielded gold, plutonium, neptunium, uranium, and sulfur. Thermal-neutron flux was measured by means of the gold and cadmium-gold detectors. The cadmium shielding was of sufficient thickness to attenuate the neutrons with energies less than 0.3 ev; hence, the difference between the resulting activation of these two foils was essentially a measure of the thermal-neutron flux. The remaining detector elements, with the exception of plutonium, have various threshold energies in the fast-neutron region. These effective thresholds are: neptunium, 0.63 Mev; uranium, 1.5 Mev; and sulfur, 3.0 Mev. Plutonium has a threshold extending into the thermal region, but an artificial threshold can be created by shielding the detector with B^{10}, the thickness of the shield determining the threshold energy. In this case, a threshold energy of 3.7 kev was created by use of 2 cm of boron shielding. For convenience, the plutonium, neptunium, and uranium foils were placed in a single boron holder. The gold and cadmium-shielded gold were exposed in steel holders, as was the sulfur.

Those neutrons with energies above the threshold energy of the detectors cause particular reactions in the detectors, with the total number of reactions produced being proportional to the number of neutrons above this energy. Calibration of the detector permits relating the resultant activity with the generating flux. By successive subtraction of the fluxes measured by each detector, the total flux is divided into broad energy

bands, which give an indication of the neutron spectrum for the particular slant range at which the detector set was exposed. Calibration and readout was accomplished by personnel of Project 2.3. A complete description of the neutron detector system is given in Reference 9.

Neutron flux versus depth was obtained by exposure of gold, cadmium-shielded gold, and sulfur detectors at various depths in the soil to a maximum of 24 inches by means of a Project 2.2 exposure container (Reference 5). The container was a cylindrical aluminum holder, $10\frac{3}{4}$ inches in outside diameter and $30\frac{3}{8}$ inches long that held four adjustable racks. Detectors were placed at various positions in the container and racks at the depths indicated in Table 2.1. The container was then placed upright in the earth

TABLE 2.1 EXPOSURE DEPTHS FOR GOLD, CADMIUM-SHIELDED GOLD, AND SULFUR DETECTORS, AND ELEMENTAL SAMPLES OF SODIUM, CHROMIUM, AND MANGANESE

Depth in Soil	Inside Container	Outside Container
in		
−4	S	—
−2	Au, Cd-Au, Na, Cr, Mn	—
$+0\frac{3}{4}$	Au, Cd-Au	Au, Cd-Au
$+2\frac{1}{4}$	Au, Cd-Au	Au, Cd-Au
$+3\frac{3}{4}$	Au, Cd-Au	Au, Cd-Au
+4	S	—
$+5\frac{1}{4}$	Au, Cd-Au	Au, Cd-Au
+6	Au, Cd-Au, Na, Cr, Mn	—
$+6\frac{3}{4}$	Au, Cd-Au	Au, Cd-Au
$+8\frac{1}{4}$	Au, Cd-Au	Au, Cd-Au
$+9\frac{3}{4}$	Au, Cd-Au	Au, Cd-Au
$+11\frac{1}{4}$	Au, Cd-Au	Au, Cd-Au
+13	S	—
+15	Au, Cd-Au, Na, Cr, Mn	—
+22	S	—
+24	Au, Cd-Au, Na, Cr, Mn	—

with approximately 6 inches protruding above the surface, refilled with soil to provide a uniform soil medium surrounding the detectors and closed with a latched cover. In addition to the detectors placed inside the container, several gold detectors were placed in the soil at various depths just outside the container in order to determine the attenuation, if any, of the thermal flux by the aluminum container wall. The depth at which these external detectors were placed is also shown in Table 2.1.

In addition to the gold and sulfur detectors, elemental samples of Na^{23}, Cr^{50}, and Mn^{55} were exposed at four levels (see Table 2.1) in the container, to obtain basic neutron activation information for these elements. A complete description of the aluminum container, all samples, and procedures used by Project 2.2 in this experiment are given in Reference 5.

Film-badge gamma dosimeters served as the primary instrumentation for measurement of integrated gamma doses. These instruments were provided by Edgerton, Germeshausen, and Grier (EG&G); Lexington Signal Depot (LSD); and the Air Force Special Weapons Center (AFSWC). Chemical dosimeters, also used to measure integrated gamma dose, were provided by the USAF School of Aviation Medicine.

The EG&G film-badge dosimeters consisted of Film Types 502, 510, 545, 548-D, and 606 contained in the EG&G pack holder. The LSD film-badge dosimeter contained Types 502 and 606 film, while the LSD film-stack dosimeter included not only these two types of films but Type 543 film as well. The LSD film-badge holder consisted of a basic plastic holder that included an open window and three filter areas incorporating aluminum, copper, and tin-lead laminate filters. The LSD film-stack dosimeter utilized a high-impact plastic case enclosing a tin-lead laminate box with the film packets distributed both inside and outside this metal box. The AFSWC film-badge dosimeters, furnished by Project 2.10, consisted of film Types 502, 606, and 510 contained in standard NBS holders. In some cases the film components of the AFSWC dosimeters were exposed without the holder.

The chemical dosimeters consisted of 1-ml vials of tetrachloroethylene. Exposure to gamma radiation liberated water-soluble acids, causing a change in the pH of the system. This resultant difference in the pH value was measured by changes in the optical transmission of the acidimetric indicator dye contained in the vials, and was related to the gamma dose through use of calibrated standards. The system shows a linear relation between radiation dose and the total acids liberated by the halogenated hydrocarbon. Acid production is linear to doses greater than 200,000 r, regardless of irradiation rate, while the fast-neutron sensitivity is less than 1 percent. In order to minimize a high thermal-neutron sensitivity, the dosimeters were shielded by a lithium container, and this container was, in turn, protected from shock and flying missiles by a $\frac{1}{4}$-inch cylindrical aluminum blast shield. A complete description of the chemical dosimeter system is given in Reference 10.

Neutron dose was determined by personnel of Project 2.3 from the flux-spectra data. The technique is based on Hurst's single-collision theory of dose contribution per neutron (described in Reference 11). The method has been used in previous operations with good success.

2.2.2 Installation and Recovery. The instrument layout for the experiment is shown in Figure 2.1. It consisted of a single exposure line extending radially outward from ground zero for 3,000 yards on an azimuth of 225 degrees.

At Station 7-2.10-9002.04A (450 yards ground range, 515 yards slant range), the decay of the induced field was monitored. A specially prepared mounting jig was installed during the first entry into the field at approximately H + 1 hour and remained in place throughout the remainder of the monitoring operation. Calibrated AN/PDR-T1B and Jordan survey meters, that were thoroughly warmed up, were carried to the jig, placed in their holders, and allowed to stabilize before readings were taken. Meter readings were taken over the period H + 1 to H + 36 hours. One Jordan meter and two T1B meters were used for this operation, being carried to and from the station for each reading. The T1B meters were obtained from and calibrated by the NTS Rad-Safe Organization. The Jordan meter was furnished by Project 2.1, and again the instrument calibration was accomplished by the furnishing agency.

In addition to the survey meters, gamma dosimeters were exposed at the monitoring station for the periods H + 1 to H + 8 hours and H + 8 to H + 36 hours. This integrated gamma dose data was used to obtain a gross check on the measured gamma dose rates.

A complete survey of the induced field was made at H + 27 hours. Measurements were made at 100-yard intervals for ground-zero distances from 200 to 2,000 yards. Both T1B and Jordan survey meters were used.

Neutron flux and spectra were measured along the exposure line shown in Figure 2.1. A cable line was installed along the 225-degree azimuth, and personnel from

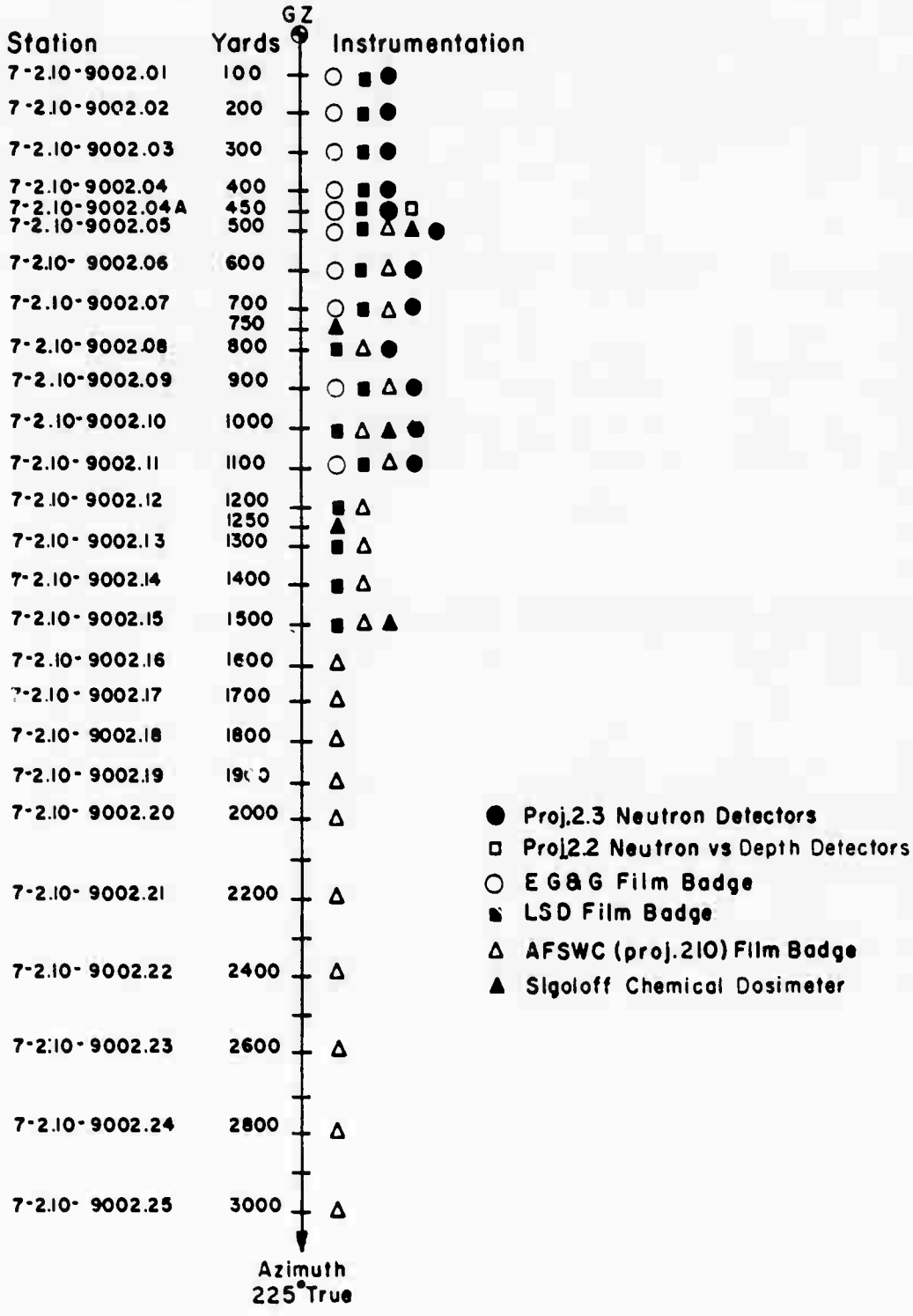

Figure 2.1 Instrumentation and area layout, Program 2.

Project 2.3 attached neutron detectors to this cable at approximately 100-yard intervals for ground distances of from 100 to 1,100 yards. Each station was elevated slightly by the use of sandbags in order to obtain a clear line of sight from the point of detonation to the detector. Recovery of the detectors was effected by attaching the outer end of the cable to a truck and towing the detectors out of the high radiation field after the shot. The detector holders were then detached from the cable and returned to the laboratory trailer located near the control point. The irradiated samples were removed from their holders and the activity counted, utilizing equipment located in the Project 2.3 laboratory trailer.

At the induced-activity monitoring station (515 yards slant range, 450 yards ground range), measurements of neutron flux versus depth were made by personnel of Project 2.2. The neutron-flux detectors and elemental samples of the various materials previously described in Section 2.2.1 were installed with their aluminum container prior to the shot. After the shot, the aluminum cylinder was removed from the station and all samples were taken to the Project 2.2 laboratory trailer for counting and analysis. The gold and sulfur sample activity was counted to determine the slow and fast neutron flux, respectively, to which they had been exposed. The manganese, sodium, and chromium samples were analyzed to determine the activity induced in them by neutron-flux exposure. For this analysis, a 100-channel gamma pulse-height analyzer was used. Since the samples exposed to the neutron flux consisted of single elements, or compounds in which only one element would be activated, only a small number of full energy peaks on the curves were produced. It was then a relatively simple matter to accomplish the analysis of the sample activation through study of full energy peaks, the areas of which could be measured and properly correlated to the gamma disintegration rate for the radioactive element. Background readings were taken after about every ten sample runs. This method of determining the specific gamma disintegration rate is called the full-energy peak-area method and is fully described in Reference 5.

The film-badge and chemical dosimeters were exposed along the 225-degree azimuth with the other instrumentation. For close-in stations, where blast or thermal damage could be expected, the film badges were enclosed in pipe holders, which consisted of 3-inch outside diameter, 6-inch long galvanized-steel pipe nipples, capped on both ends with standard 3-inch galvanized-steel pipe caps. One of the pipe caps was fitted with an eyebolt by which the pipe holder was attached to the neutron cable. At more-distant stations, the dosimeters were displayed on exposure stakes; the dosimeters were held in place by tape and protected from thermal damage by covering them with aluminum foil. Calibration, development, and dose determination were accomplished by the agency which provided the instrument.

The Sigoloff-type chemical dosimeters were displayed on "goal posts" at the positions indicated in Figure 2.1. These goal posts were merely pairs of stakes driven into the ground with a crossbar suspended between them. The chemical dosimeters, contained in the lithium-aluminum can, were attached to the crossbar. The exposed dosimeters were read and interpreted by the furnishing agency, the USAF School of Aviation Medicine.

Chapter 3
RESULTS

3.1 INDUCED ACTIVITY

Data pertaining to the decay of the induced field, as determined by survey-meter readings at Station 7-2.10-9002.04A (515 yards slant range) is presented in Table 3.1 and Figure 3.1.

The H+1 to H+8 and the H+8 to H+36 integrated gamma doses measured at the same station are given in Table 3.2. This table also presents the calculated gamma doses for these periods, which were obtained by integration of the curves presented in Figure 3.1 over these time intervals.

Table 3.3 is a record of the induced field survey conducted at H+27 hours along the 225-degree azimuth.

3.2 NEUTRON FLUX

The threshold-detector results versus distance are presented in Table 3.4. The data from the table is presented graphically in Figure 3.2, in which the flux times slant range squared is plotted versus the slant range for each of the measured fluxes. This type of presentation corrects for the law of inverse squares inherent in the geometry of measuring intensity from a point source.

3.3 NEUTRON FLUX VERSUS DEPTH

Neutron flux data, as obtained from the gold, cadmium-shielded gold, and sulfur detectors, placed at various depths in the soil at 515 yards slant range, is given in Table 3.5. This data is presented graphically in Figures 3.3 and 3.4, which give curves for flux versus depth for fast (>3 Mev) and slow (<0.3 ev) neutrons, respectively.

Table 3.6 is a record of the specific zero time gamma activity generated in the various elemental samples exposed in the Project 2.2 aluminum container at Station 7-2.10-9002.04A. The results for the (n, γ) reactions are given in terms of disintegrations per second per gram of respective sample at zero time. Results were calculated by the full-energy peak-area method previously mentioned (Reference 5). For the reactions indicated, the photon energy peaks used to calculate the induced activity were as follows:

$$Mn^{55}(n, \gamma)\, Mn^{56} — 0.845 \text{ Mev}$$

$$Na^{23}(n, \gamma)\, Na^{24} — 1.38 \text{ Mev}$$

$$Cr^{50}(n, \gamma)\, Cr^{51} — 0.320 \text{ Mev}$$

The specific activities induced in the various soil elements as a function of depth are shown in Figure 3.5.

3.4 NEUTRON AND GAMMA DOSE VERSUS DISTANCE

Neutron dose results, as calculated from the flux-spectra data, are presented in

Table 3.7, which gives both the actual values determined for the ambient atmospheric conditions at shot time as well as the dose values corrected for a condition of unit density. These same results are presented graphically in Figure 3.6, which in addition, includes a predicted curve for a weapon with a yield of 1.22 kt as determined using the

TABLE 3.1 GAMMA FIELD INTENSITY VERSUS TIME, 8-9 SEPTEMBER, STATION 7-2.10-9002.04A (515 YARDS SLANT RANGE, 450 YARDS GROUND RANGE)

Time After Shot		T1B (Average of 2 Instruments with 2 Monitors)	Jordan (Average for 2 Monitors)
hr-min	min	r/hr	r/hr
0:55	55	2.75	5.75
1:58	118	2.41	3.8
2:58	178	2.11	2.9
3:58	238	1.85	2.2
7:06	426	1.34	1.88
7:55	475	1.25	1.55
13:30	810	0.93	1.23
14:57	897	0.79	1.11
27:10	1,630	0.44	0.6
32:18	1,938	0.35	Erratic
35:58	2,158	0.30	Erratic

methods and data presented in TM 23-200 (Reference 12).

Results obtained from the initial-gamma dose versus ground distance documentation are summarized in Table 3.8. Figure 3.7 shows the same data in graphical form and, for comparison purposes, includes a curve for initial-gamma dose versus slant range

TABLE 3.2 INTEGRATED GAMMA DOSES FOR SPECIFIC EXPOSURE INTERVALS AT STATION 7-2.10-9002.04A (515 YARDS SLANT RANGE, 450 YARDS HORIZONTAL RANGE)

Exposure Interval	Measured Dose				Dose from Integration of Dose Rate Curves Figure 3.1
	EG&G Film Badge	LSD Film Badge	AFSWC Film Badge	Average	
	r	r	r	r	r
H+1 to H+8	16	No results	10.3	13.7	18.1 (Jordan) 12.8 (T1B)
H+8 to H+36	22.5	10.3	13.5	15.4	24.9 (Jordan) 18.2 (T1B)

for a 1.22-kt weapon as derived from curves presented in Reference 12.

It should be noted that the data presented in Table 3.8 and Figure 3.7 represent both corrected and uncorrected initial-gamma dose values. The method by which these values were corrected is discussed in the next chapter of this report.

TABLE 3.3 GAMMA FIELD INTENSITY VERSUS RANGE, 9 SEPTEMBER 1957 AT H + 27 HOURS, AZIMUTH 225 DEGREES

Ground Range	Slant Range	Dose Rate	
		T1B Survey Meter	Jordan Survey Meter
yd	yd	mr/hr	mr/hr
200	320	2,620	3,800
300	391	1,300	1,550
400	472	790	830
500	558	330	410
600	650	180	210
700	744	85	125
800	837	58	62
900	934	35	40
1,000	1,030	20	21
1,100	1,128	13	12
1,200	1,225	8	8
1,300	1,325	5.8	5.5
1,400	1,420	3.6	4.0
1,500	1,520	2.9	3.0
1,600	1,620	2.4	2.4
1,700	1,720	1.9	1.7
1,800	1,815	1.45	1.6
1,900	1,915	1.5	1.4
2,000	2,015	1.38	1.2

TABLE 3.6 ACTIVITY AT ZERO TIME IN DISINTEGRATIONS PER SECOND PER GRAM, STATION 7-2.10-9002.04A (PROJECT 2.2 DATA)

Activity Observed	Assumed Half Life	Height of Sample with Respect to Ground Surface, in			
		+2	-6	-15	-24
Mn^{56}	2.58 hr	4.56×10^{7}	4.88×10^{7}	1.37×10^{7}	2.72×10^{6}
Na^{24}	15.0 hr	7.63×10^{5}	6.86×10^{5}	2.19×10^{5}	4.13×10^{4}
Cr^{51}	27.8 day	1.02×10^{4}	1.20×10^{4}	3.85×10^{3}	7.70×10^{2}

TABLE 3.8 INITIAL GAMMA DOSE VERSUS DISTANCE, AZIMUTH 225 DEGREES

Horizontal Distance	Slant Range	Measured Gamma Dose, Uncorrected			Equivalent Free Air Dose, Corrected*			Sigoloff Chemical Dosimeter
		EG&G Film Badge	LSD Film Badge	AFSWC Film Badge in NTS Holder	EG&G Film Badge	LSD Film Badge	AFSWC Film Badge in NTS Holder	
yd	yd	r	r	r	r	r	r	r
100	270	$\sim 5 \times 10^6$ †	$>10^4$ †	—	$\sim 5 \times 10^6$	$>10^4$	—	—
200	320	$\sim 2 \times 10^6$ †	$>10^4$ †	—	$\sim 2 \times 10^6$	$>10^4$	—	—
300	391	2.1×10^5 †	$>10^4$ †	—	2.56×10^5	$>10^4$	—	—
400	472	4.6×10^4 †	$\sim 10^4$ †	—	5.33×10^4	$\sim 10^4$	—	—
450	515	1.9×10^4 †	$\sim 10^4$ †	—	2.06×10^4	$\sim 10^4$	—	—
		1.9×10^4	—	—	1.78×10^4	—	—	—
500	558	10^4 †	5,800 †	>1,500 †	10,250	5,023	>1,500	3,900
600	650	3,400 †	2,000 †	>1,500 †	3,163	1,428	>1,500	—
				>1,500	—	—	>1,500	—
700	744	1,700 †	960 †	>1,500 †	1,573	660	>1,500	—
750	790	—	—	—	—	—	—	880
800	837	—	685 †	1,400 †	—	584	1,462	—
		—	—	1,300	—	—	1,192	—
900	934	580 †	385 †	715 †	549	311	715	—
		500	—	665	433	—	598	—
1,000	1,030	—	235 †	350 †	—	205	345	230
1,100	1,128	240 †	170 †	208 †	248	163	209	—
1,200	1,225	—	106	120	—	96	110	—
				135‡	—	—	125	—
1,250	1,275	—	—	—	—	—	—	82
1,300	1,325	—	67	76	—	61	70	—
1,400	1,420	—	43	44	—	40	41	—
1,500	1,520	—	27.5	29	—	26	27	36
1,600	1,620	—	—	20	—	—	19	—
				32‡	—	—	31	—
1,700	1,720	—	—	14	—	—	14	—
1,800	1,815	—	—	10	—	—	10	—
1,900	1,915	—	—	6.7	—	—	6.7	—
2,000	2,015	—	—	4.9	—	—	4.9	—
				7.4‡	—	—	7.4	—
2,200	2,215	—	—	2.6	—	—	2.6	—
2,400	2,410	—	—	1.4	—	—	1.4	—
2,600	2,610	—	—	0.83	—	—	0.83	—
2,800	2,810	—	—	0.54	—	—	0.54	—
3,000	3,010	—	—	0.38	—	—	0.38	—

* Measurements corrected for neutron effects on film, and, where applicable for gamma dose from neutron capture radiation produced by pipe holders plus gamma attenuation caused by holder.

† Measurements made inside steel pipe holder.

‡ Measurements made without NBS film-badge holder.

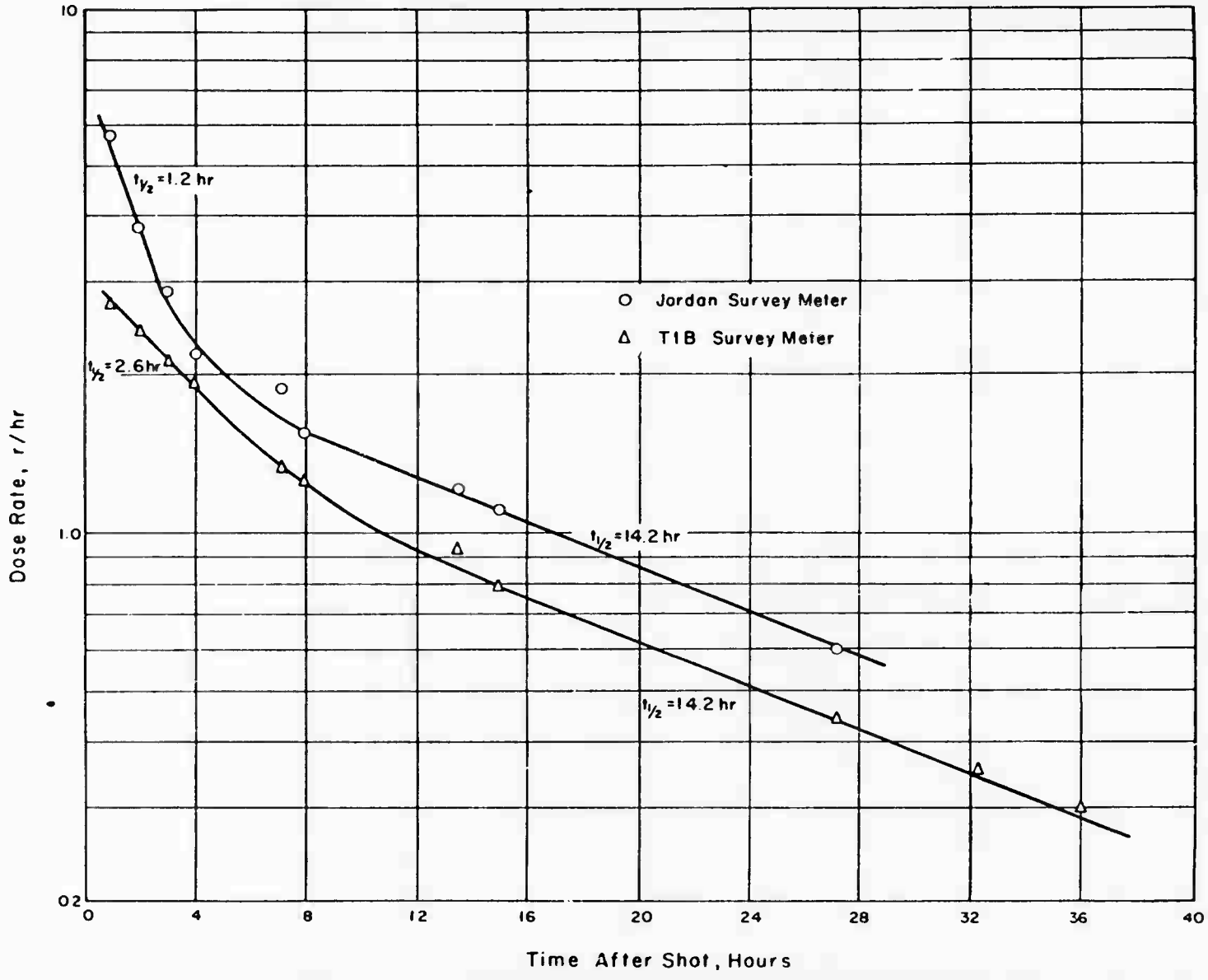

Figure 3.1 Dose rate versus time, Station 7-2.10-9002.04A, 515 yards slant range.

Figure 3.5 Specific activities produced in exposed elemental samples at Station 7-2.10-9002.04A, 515 yards slant range.

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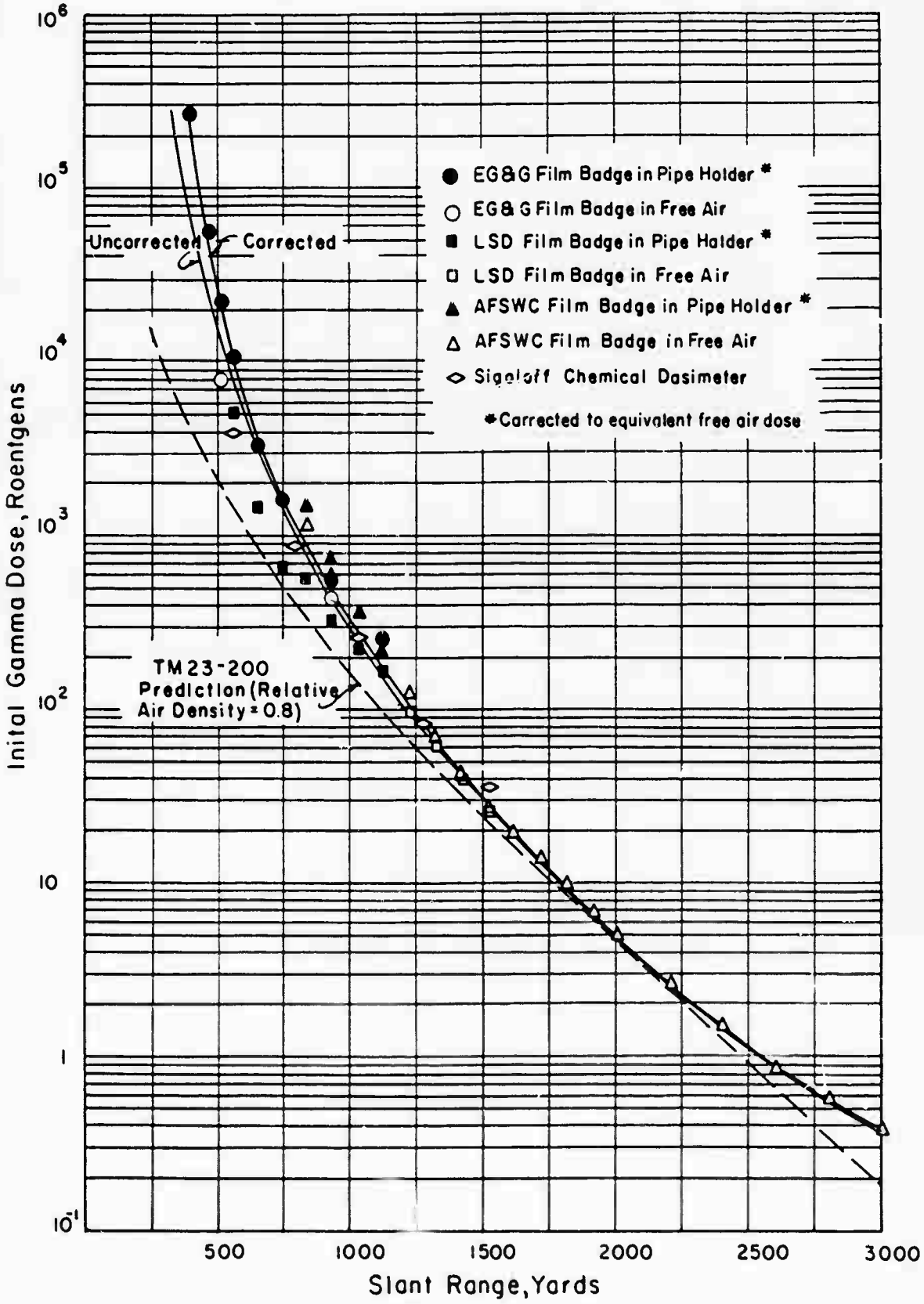

Figure 3.7 Initial gamma dose versus slant range.

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Chapter 4
DISCUSSION

4.1 INDUCED ACTIVITY

The decay curves for the induced field obtained at Station 7-2.10-9002.04A (515 yards slant range) have been previously presented in Figure 3.1. The apparent intensity of the field, as well as its decay rate at early times, appears to be dependent on the instrument with which the measurements were made. The T1B sees an early decay rate indicative of an element with a 2.6-hour half life, which is in excellent agreement with the known 2.58-hour half life of Mn^{56}. The Jordan survey meter, on the other hand, appears to see a stronger early field with a half life of approximately 1.2 hours during the interval between H+1 and H+3 hours. Since this instrument behaved erratically during the later part of the survey and since the early decay that it indicated cannot be explained by the known half lives of Mn^{56} and Na^{24}, which must have been the principal radiation contributors during these early times, the data obtained with this instrument is considered suspect and, therefore, is not used in the drawing of any conclusions. At times later than approximately H+10 hours, when only the 15.0-hour Na^{24} activity was significant, both instruments are in agreement as to rate of decay, although the Jordan meter readings remain somewhat higher than the concurrent T1B readings. This is probably due to inherent differences in the instruments or to calibration errors. The measured half life of the activity at these later times (14.2 hours) is in satisfactory agreement with the known Na^{24} half life. As the result of a comparison between the gamma doses determined by integrating the meter dose-rate readings and by film-badge dosimetry as presented in Table 3.2, it becomes apparent that there is much better agreement between the T1B and film-badge doses than between the Jordan and film-badge values. As an average, the Jordan doses exceed the film-badge doses by 46 percent, whereas the T1B doses vary by a maximum of 18 percent from the film-badge doses. This again indicates the greater reliability of the T1B. Since the generally quoted accuracy of film badges is ± 20 percent, the agreement existing between the integrated T1B and film-badge doses is considered sufficient to give gross confirmation of the validity of the T1B measurements.

The survey of the complete induced field that produced the results presented in Table 3.3 was conducted along the single azimuth of 225 degrees. This particular direction was selected because the cloud from the shot had been observed to go directly opposite to this direction, thus reducing the likelihood that fallout contamination would be present. As in the case of documentation of the induced-field decay, both the T1B and Jordan instruments were used. As before, the Jordan dose-rate readings were generally higher than those of the T1B. By use of the survey data presented in Table 3.3 and the decay curves given in Figure 3.1, the H+1 hour field intensities can be reconstructed. The decay factor for the interval H+1 to H+27 hours as determined from Figure 3.1 is approximately 6.3 for the T1B, and multiplication of the Table 3.3 H+27-hour dose-rate values by this factor will yield equivalent H+1-hour dose rates. For example, the H+1 dose rate at the 320-yard (slant range) station, the station closest to ground zero at which survey measurements were made, is found to be 16.4 r/hr. Extrapolations to times earlier than H+1 hour are not possible from the data obtained by this experiment. Since the primary contributor to the induced field activity at early times would be Al^{28}

rather than Mn^{56} or Na^{24}, the reader is cautioned against using the experimental data in any induced-activity study relating to times earlier than H + 1 hour. No attempts at extrapolating the Jordan data were made because of the questionability of this data.

Since the objective of this portion of the experiment was the documentation of the intensity and decay of the Laplace neutron-induced field, rather than the verification or development of any prediction method, no attempt has been made to use the data for this latter purpose. It is hoped, however, that the data will prove useful in serving as a check for any prediction method that may be proposed.

4.3 NEUTRON FLUX VERSUS DEPTH

The results obtained in the measurement of thermal (gold) and fast (sulfur) neutron fluxes versus soil depth, as presented in Table 3.5, serve to confirm the results of similar measurements made by Project 2.2 during Shots Wilson and Owens (Reference 5). As observed on these earlier shots, the thermal flux was found to peak at a soil depth of approximately 4 inches, whereas the fast flux degraded rapidly with depth.

As expected, the activity induced in the various elemental samples was primarily the result of n, γ reactions produced in the sample materials, although some possible competing reactions such as n, 2n were indicated. The activities produced were those of Na^{24}, Mn^{56}, and Cr^{51}. Figure 3.5 shows graphically the relative specific activation of the various elements as a function of depth. It is noted that the specific activation is reasonably well related to the neutron cross section for the reaction involved. For any comparison of the activity that these radioactive isotypes will contribute in any particular induced soil situation, consideration must be taken of the relative abundance of the parent elements in the soil.

4.4 NEUTRON AND GAMMA DOSE VERSUS DISTANCE

Figure 3.6 includes a comparison of the measured neutron dose corrected for unit air density as a function of slant range with that predicted by the current TM 23-200 prediction method. The comparison indicated that for slant ranges between 300 and 700 yards, the Laplace measured values exceed those obtained from TM 23-200 for a 1.22-kt fission weapon by an average factor of 2.6. As the stated reliability of the prediction method indicates that for certain experimental devices the predicted values can be low by a factor of as much as four, the agreement is considered satisfactory. The experimental data is representative of ission devices, however, and should be useful in improving the neutron dose prediction techniques

Table 4.2 presents a further comparison of neutron dose per kiloton of yield as measured at a slant range of 500 yards for Shots Owens, Wilson, Laplace, and Priscilla. The dose values have all been corrected to unit air density (ρ = 1.0) to permit more accurate comparison. The results of this comparison generally parallel those of the previous lower energy neutron flux comparisons, with the Laplace dose being less than that of Owens, comparable to that of Wilson, and greater than that of Priscilla.

The initial gamma doses as a function of slant range as presented in Figure 3.7 agree with prediction to within a maximum factor of about three for ranges in excess of 700 yards, which is greater than the stated reliability factor of two of the prediction method for a weapon of this yield. At closer distances, even greater discrepancy is noted. Since the variation increases with decreasing slant range, one might suspect the induced residual radiation dose as being a possible cause of the variation. An evaluation of the dose attributable to the induced field for the period zero time to recovery time (H + 55 minutes), however, clearly shows that the discrepancy is too great to be explained in this manner. As indicated in Table 3.8, the in-close measurements are admittedly questionable; even at the greater ranges, the agreement between the various types of dosimeters was not exceptional, although the disagreement was usually less than a factor of two. For this reason some of the apparent variation may be the result of the inherent inaccuracy of the instrumentation in measuring very-large doses.

Another possible explanation for the discrepancy between measured and predicted doses is the effect of neutrons on the dosimeters. Since practically all of the in-close

TABLE 4.2 COMPARISON OF NEUTRON DOSE PER KT FOR SHOTS OWENS, WILSON, LAPLACE, AND PRISCILLA FOR UNIT AIR DENSITY CONDITIONS (ρ = 1.0)

Slant Range	Neutron Dose per Unit Yield, rep/kt			
	Owens	Wilson	Laplace	Priscilla
yd				
500				

dose data was obtained by film-badge dosimeters, an attempt was made to correct these measurements for neutron effects. The corrections also included a correction for the shielding effect of the steel pipe holders in which the close-in dosimeters were exposed for blast and thermal protection. The following equation obtained from Radiological Division, U.S. Army Chemical Warfare Laboratories (Reference 13) was used in making these corrections.

$$D = \frac{D_m - (5.04 \times 10^{-10})\,(N_{Au}) - D_S - D_F}{F_T}$$

Where: D = corrected gamma dose, r

D_m = measured gamma dose, r

N_{Au} = thermal neutron flux, n/cm^2

D_S = apparent gamma dose, r, caused by response of film to thermal energy (slow) neutrons $= \left(\frac{N_{Au}}{3.0 \times 10^9}\right)$

D_F = apparent gamma dose, r, caused by response of film to high energy (fast) neutrons = 0.043 × neutron dose (rep)

F_T = gamma radiation transmission factor for steel pipe holders

The second term in the numerator of the expression is the correction for the gamma dose resulting from neutron-capture gamma photons generated in the steel pipe holder. Specifically, 5.04×10^{-10} is the capture gamma roentgen dose per unit of gold flux for

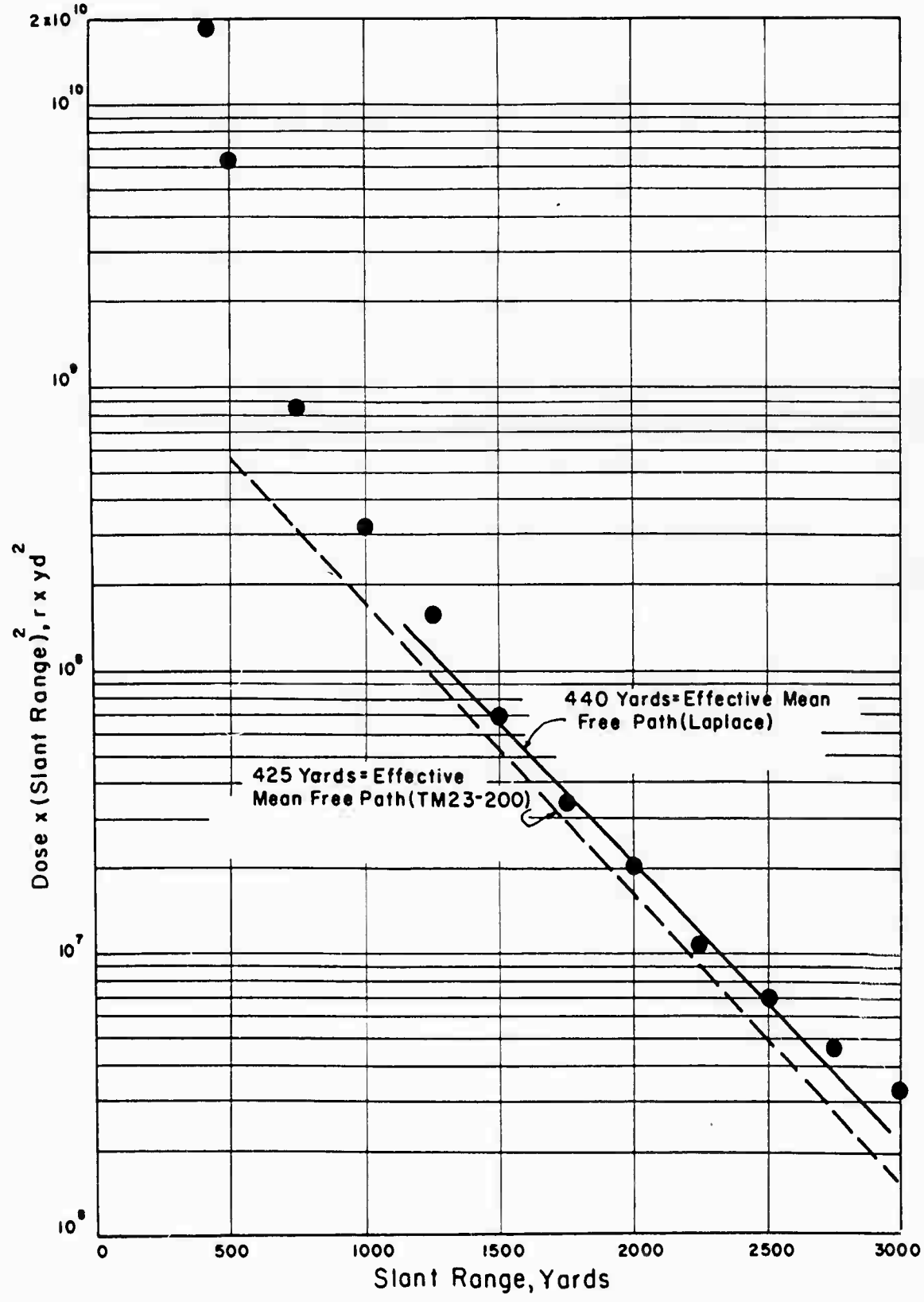

Figure 4.1 Initial gamma dose times slant range squared versus slant range.

the particular pipe holder used in these measurements. Film-neutron-response correction factors are averages of the individual response factors of the films used. The transmission factor (F_T) was assumed to be 0.77 in the region where the dose is predominantly from fission-product gamma rays and 0.87 where the gamma radiation is primarily from a $N^{14}(n, \gamma)N^{15}$ source. It was assumed that the n, γ dose was negligible at ground zero, equal to the fission-product dose at 1,500 yards and seven times this dose at 3,000 yards (Reference 6).

The result of applying these corrections to the experimental data is presented in Table 3.8 and shown graphically in Figure 3.7. Since the assumptions on which the corrections are based are subject to some question, no great confidence can be placed in the corrected data. However, despite possible inaccuracy of the measurements, the correction method, and the contribution to the total dose by the residual field, the magnitude and consistent fashion by which the measured doses exceed prediction indicates that Laplace produced a more-intense gamma source than would be expected from a 1.22-weapon of the type used in deriving the TM 23-200 prediction curves.

A plot of gamma dose times slant range squared versus slant range is presented in Figure 4.1. This plot eliminates the geometrical attenuation effect and permits evaluation of the gamma mean free path in air. As shown on the figure, an effective mean free path of 440 yards was determined for distances between 1,500 and 2,500 yards, which compares favorably with a 425-yard effective mean free path determined from TM 23-200 curves for a relative air density of 0.8.

Chapter 5
CONCLUSIONS and RECOMMENDATIONS

5.1 CONCLUSIONS

The neutron-induced gamma-radiation field generated by Shot Laplace and its decay from H+1 to H+36 hours were successfully documented. The observed decay rate indicated the presence of radionuclides having half lives of 2.6 and 14.2 hours, which are in good agreement with the known half lives of Mn^{56} and Na^{24}. These two radionuclides are therefore indicated as the principal contributors to the radioactive field during the time observations were made. Gross agreement between film-badge results for total dose and the dose calculated by integration of the dose-rate curve for the period H+1 to H+8 and H+8 to H+36 serves to roughly confirm the validity of the measurements made for the decay documentation. The survey of the neutron-induced field at H+27 hours indicated dose-rate levels ranging from 2,620 mr/hr at 320 yards slant range to 1.38 mr/hr at 2,015 yards. When extrapolated back to H+1 hour, the 320 yard reading was found to be equivalent to 16.4 r/hr.

The neutron flux and spectra of Shot Laplace were successfully documented for slant ranges from 270 to 1,130 yards.

The data obtained in the documentation of thermal (gold) and fast (sulfur) neutron fluxes with depth in soil confirmed earlier observations that thermal flux peaks at a soil depth of approximately 4 inches, whereas the high-energy flux degrades rapidly with depth.

Neutron irradiation of elemental samples of sodium, chromium, and manganese produced the induced activities of Na^{24}, Cr^{51}, and Mn^{56}. The specific activation was reasonably well related to the cross sections of the reactions involved.

The measured neutron dose exceeded that predicted by TM 23-200 by an average factor of 2.6 for ranges between 300 and 700 yards. Although this is within the prediction-method reliability factor of four quoted for weapons of this type, the Laplace data is considered representative of devices and should be used to improve the prediction techniques as they apply to a weapon of this type. The neutron dose per kiloton of yield of at a slant range of 500 yards for Shot Laplace was that produced by Shot Owens at the same slant range, produced by Wilson and that of Priscilla rep/kt).

The initial gamma dose data showed that Laplace produced a greater-than-predicted initial gamma dose at all ranges, with the greatest discrepancy occurring at the close-in ranges. The measured gamma doses ranged from 25,600 r at 390 yards slant range to less than 1 r for ranges in excess of 2,500 yards. The effective mean free path of the initial gamma radiation at ranges in excess of 1,500 yards was 440 yards, slightly greater than the value predicted (using a relative air density of 0.8) of 425 yards.

5.2 RECOMMENDATIONS

It is recommended that the induced-activity data obtained by this experiment be utilized in the verification or development of induced-activity-prediction methods. It is further recommended that the data for neutron and gamma dose versus distance be considered in any re-evaluation of applicable TM 23-200 prediction curves,

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PA995280 U FIELD/GROUP ●●●●●● P1808+ P1803)-Co.

UNCLASSIFIED TITLE

OPERATION PLUMBBOB. PROGRAM 2. NEUTRON AND GAMMA RADIATION FROM SHOT LAPLACE,

ABSTRACT

(U) THE OBJECTIVES OF THIS EXPERIMENT WERE TO DETERMINE, FOR SHOT LAPLACE, A 1.22-KT DEVICE FIRED LATE IN OPERATION PLUMBBOB: (1) INTENSITY AND DECAY OF THE NEURON-INDUCED GAMMA-FIELD; (2) NEUTRON FLUX AND SPECTRA AS A FUNCTION OF DISTANCE; (3) NEUTRON FLUX AS A FUNCTION OF SOIL DEPTH WITH CERTAIN SELECTED DETECTORS; AND (4) NEUTRON DOSE AND INITIAL GAMMA DOSE AS A FUNCTION OF DISTANCE. KEYWORDS: NUCLEAR EXPLOSION TESTING; NTPR (NUCLEAR TEST PERSONNEL REVIEW); AND NEVADA TEST SITE.

POSTING TERMS ASSIGNED

DETECTORS
USE DETECTORS

FUNCTION OF SOIL DEPTH
USE DEPTH
FUNCTIONS
SOILS

GAMMA RADIATION
USE GAMMA RAYS

NEUTRON FLUX
USE NEUTRON FLUX

FUNCTION OF DISTANCE
USE FUNCTIONS
RANGE(DISTANCE)

GAMMA DOSE
USE DOSAGE
GAMMA RAYS

NEUTRON DOSE
USE DOSAGE
NEUTRONS

NUCLEAR EXPLOSION TESTING
* ●●● NUCLEAR EXPLOSION TESTING)-Co,

Neutron spectrum)-Co.
* Nuclear radiation)-Co.

PHRASES NOT FOUND DURING LEXICAL DICTIONARY MATCH PROCESS

PROGRAM 2

1.22-KT DEVICE

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