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OPERATION HARDTACK

Projects 2.9/2.12b
Gamma Dose From Very-Low-Yield Bursts

April-October 1958

Headquarters Field Command
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Operation HARDTACK
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Project 2.9 participated in Shot Quince and Shot Fig with the following objectives: (1) to document the initial gamma dose versus ground range and (2) to measure the total gamma dose received at a point as a function of time, at distances of military interest, for a fractional-kiloton nuclear surface burst. Project 2.12b participated in Shot Hamilton and Shot Humboldt with the following objectives: (1) to provide gamma-dose measurements in support of the biomedical Project 4.2 and (2) to document the initial gamma dose versus ground range.

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.

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FOREWORD

This report presents the final results of two 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.

ABSTRACT

Project 2.9 participated in Shot Quince and Shot Fig with the following objectives: (1) to document the initial gamma dose versus ground range and (2) to measure the total gamma dose received at a point as a function of time, at distances of military interest, for a fractional-kiloton nuclear surface burst.

Project 2.12b participated in Shot Hamilton and Shot Humboldt with the following objectives: (1) to provide gamma-dose measurements in support of the biomedical Project 4.2 and (2) to document the initial gamma dose versus ground range. In addition, secondary objectives of this project were to document residual radiation intensities and to determine the field gamma-decay rate.

These objectives were accomplished by measuring the dose with film badges which were exposed at various ranges and azimuths, observing the dose on the film badges of the incremental-gamma-dose recorders (Emmett devices), and by field surveys with portable instruments.

Project 4.2 was furnished gamma-dose information for their stations.

The following conclusions are based on the results from Shots Fig, Hamilton, and Humboldt and apply to fractional-kiloton-yield devices tested:

1. Initial gamma doses in the 300 to 900 yard range may be extrapolated from TM 23-200 data with confidence, for surface bursts.

2. An air burst will deliver at least twice the initial gamma dose of a surface burst for the same yield, at distances up to 300 yards from detonation. At greater distances the difference between the doses received from the air burst and the surface burst decreases, and the doses become nearly equal to 1,000 yards.

3. Lethal doses (600 r) of initial gamma radiation are received at approximately 150 yards from the point of detonation the 7.8-ton Humboldt low air burst, while the delivery crews, in the open, would receive 15 r of initial gamma radiation at ranges 575 yards respectively.

4. The observed variation of gamma dose with azimuth for the surface burst is probably caused by the contribution of dose from the transient cloud.

5. The residual gamma fields produced by low air bursts detonated on wooden towers are very small, less than 200 yards radius after 15 minutes, for the 10 r/hr isodose line. This field is due to fission-product radiation, probably from contaminated tower materials.

6. The alpha-contamination levels from low air bursts at distances greater than 100 yards are considered to be an insignificant hazard.

PREFACE

Project 2.9 made the initial gamma measurements for the fractional-kiloton detonations at the Eniwetok Proving Ground. Subsequent to the cessation of operations at Eniwetok, Project 2.12b was initiated on short notice to make similar measurements on similar devices at the Nevada Test Site. Since the objectives, operations, and findings of the two projects are so interwoven, it was deemed advisable to prepare a combined report, rather than two similar reports with multiple cross-referencing throughout.

The authors wish to express their appreciation to Edgerton, Germeshausen and Grier, Inc., for the use of their gamma source for calibration of film badges and to G. Carp and R. Larrick, U. S. Army Signal Research and Development Laboratory, for their advice in the operation of the Emmett device and the processing and interpretation of the film badges.

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FIGURES

GAMMA DOSE from VERY-LOW-YIELD BURSTS

OBJECTIVES

The objectives of Project 2.9 were: (1) to document the initial gamma dose versus ground range and (2) to measure the total gamma dose received at a point as a function of time, at distances of military interest, for a fractional-kiloton nuclear surface burst.

The primary objectives of Project 2.12b were: (1) to provide gamma-dose measurements in support of the biomedical Project 4.2 and (2) to document the initial gamma dose versus ground range for Shots Hamilton and Humboldt. In addition, secondary objectives of this project were to document residual radiation intensities and to determine the field gamma-decay rate.

BACKGROUND

Very-low-yield weapons are being considered for use in both ground and air warfare. In ground warfare their primary tactical use would be in close-support operations. Here, the initial gamma and neutron radiation is considered to be the controlling criterion for safe employment of such weapons (Reference 1).

Initial-gamma radiation dose has been studied at almost all tests since Operation Sandstone by the exposure of film badges at various distances from ground zero. These measurements have been limited to yields greater than the very-low yields of Shots Fig, Hamilton, and Humboldt. Measurements made at Operation Jangle (Reference 2) and Operation Plumbbob (Reference 3) provide the most appropriate background data for this project. These references indicate that the initial gamma radiation from a surface burst is reduced by 50 percent compared to an equivalent air burst. Therefore, the air burst would have a greater gamma lethality radius than an equivalent surface burst.

Since fractional-kiloton weapons will probably be employed as low air or surface bursts, the likelihood of fallout and neutron-activated soil contamination exists. Furthermore, since the low-yield weapons would be inefficient in terms of fissioning of nuclear materials, the likelihood of alpha contamination exists. Project 2.10 documented the alpha and gamma contamination levels for the surface Shots Quince and Fig (Reference 4), but was not operational for the air-burst Shots Hamilton and Humboldt. Project 2.12b, with little additional effort, assumed these tasks for these events.

THEORY

With any nuclear detonation, various nuclear radiations are emitted during and after the explosion. Since this report deals with the gamma radiation, the phenomena associated with this radiation will be discussed here briefly.

It is convenient to consider the gamma radiation as being divided into two categories, initial and residual. For this project, the initial radiation is arbitrarily taken as that emitted during the first minute after the explosion. This radiation results from many nuclear reactions and effects, of which three predominate (References 5 and 6):

1. Prompt radiation accompanying the fission process, which is emitted during the first few microseconds.
2. Nitrogen-capture photons emitted from the capture of thermal neutrons by nitrogen in

the atmosphere and in the weapon's high explosives. These photons have high energies (5 to 10 Mev) and account for almost all the dose received from a few milliseconds to a quarter of a second. For high-neutron-flux fission weapons (< 20 kt), this dose accounts for 50 percent of the total initial gamma dose at 1,000 yards and 90 percent at 3,000 yards.

3. Fission-product gamma rays emitted from the fireball and cloud. These rays have a mean energy of about 1 Mev and account for the dose received after the first quarter second. This dose drops off rapidly as the fission products decay and the fireball rises.

Reference 7 contains a collation of initial gamma-dose data from many previous operations. By plotting experimental values of dose-per-unit yield times distance squared versus distance for surface bursts of low- and intermediate-yield weapons, it was found that the straight line of best fit is described by the following equation.

$$\frac{D R^2}{W h_{eff}} = 1.93 \times 10^9 \, e^{-\rho R/324} \quad (1)$$

Where:
- D = initial gamma dose, roentgens
- R = distance from detonation, yards
- W = yield, kt
- h_{eff} = effective hydrodynamic scaling factor = 1 for subkiloton bursts
- ρ = relative air density

The residual nuclear radiation is defined as that emitted after 1 minute following the detonation. This radiation arises from deposited bomb residues (fission products, unfissioned uranium and plutonium, neutron-activated bomb materials) and from activity induced by neutrons captured in various elements present in the earth or in substances in the vicinity of the detonation. In the case of an air burst, the fission products and bomb residues are dispersed widely and usually do not produce a military problem. However, the induced activity in the soil near ground zero may constitute a military problem for early operations in this area.

Induced gamma activity in soil results when neutrons are captured by nuclei of certain soil elements. The resulting products are radioactive isotopes of the original absorbing elements and can be expected to be unstable. These decay to stable isotopes, usually with the emission of a gamma ray. In the case of most soils, the significant elemental constituents that become activated and cause the induced gamma field are aluminum, manganese, and sodium (with half lives of 2.3 minutes, 2.6 hours, and 15 hours, respectively). Project 2.12c investigated soil-induced activity, and a detailed discussion of this phenomenon can be found in the report of that project (Reference 8).

OPERATIONS

Project 2.9 participated in Shots Quince and Fig at Site Yvonne, Eniwetok Proving Ground (EPG). Project 2.12b participated in Shots Hamilton and Humboldt at Frenchman Flat and Area 3, respectively, Nevada Test Site (NTS). Table 1 lists some of the characteristics and conditions of detonation of these shots.

EPG Operations. Stations were placed as follows: (1) thirty-six film-badge stake stations on land, (2) four Emmett devices on land, (3) eight film-badge stations along the Project 2.4a west neutron line on land and water, and (4) seven film-badge stations aloft at Project 2.4a stations, hung vertically from the Project 2.11 balloon.

The location of the film-badge stations on land, water, and the balloon are shown in Figure 1. Station distances and azimuths for all stations are tabulated in Table 2. The station array is far from ideal because of the limited land mass and obstructions, but is the best compromise of available locations with line of sight to ground zero.

The project participated in Shots Quince and Fig with identical instrumentation being used for both events. The dosimeter film badges were installed several days before the shot and recovered at approximately H + 24 hours. Film badges were calibrated immediately following

TABLE 1 SHOT DATA

Shot	Burst Height	Support	Yield	Air Temp	Relative Humidity	Atmospheric Pressure	Relative Air Density
	ft		tons	C	pct	mb	
Quince	0	Ground					
Fig	0	Ground		30	77	1,007	0.90
Hamilton	50	Wooden Tower	1.17 ± 0.06	15.7	31	891	0.83
Humboldt	25	Wooden Tower	7.8 ± 0.7	7.4	46	885	0.85

TABLE 2 STATION LOCATIONS, SHOTS QUINCE AND FIG

Station Number	Type	Distance	Azimuth
		yds	deg
South Line			
35	Land	30	143
1	Land	90	135
13	Land	99	150
14	Land	198	150
36	Land	200	165
15	Land	293	150
16	Land	400	147
17	Land	497	147
18	Land	596	147
19	Land	723	145
20	Land	805	145
21	Land	873	145
North Line			
6	Land	100	330
7	Land	100	315
8	Land	100	300
5	Land	105	350
24	Land	199	330
23	Land	200	315
22	Land	200	300
26	Land	298	319
25	Land	301	330
27	Land	401	315
28	Land	402	329
30	Land	500	328
29	Land	501	315
32	Land	601	329
31	Land	602	315
34	Land	701	330
33	Land	711	315

Station Number	Type	Distance	Azimuth
		yds	deg
West Line			
W-1	Land	30	233
10	Land	86	242
W-2	Land	100	233
11	Land	103	205
W-3	Buoy	247	233
W-4	Buoy	344	233
W-5	Buoy	444	233
W-6	Buoy	603	233
W-7	Buoy	817	233
W-8	Buoy	1,040	232
Balloon Line			
B-1	Balloon	121	165
B-2	Balloon	133	165
B-3	Balloon	173	165
B-4	Balloon	227	165
B-5	Balloon	283	165
B-6	Balloon	347	165
B-7 *	Balloon	410	165
Emmett Station			
E-1	Emmett	100	324
E-2	Emmett	200	323
E-3	Emmett	200	304
E-4	Emmett	400	322
Miscellaneous Stations			
3	Land	40	61
4	Land	49	16
2	Land	60	85
12	Land	100	180
9	Land	101	270

* Station destroyed.

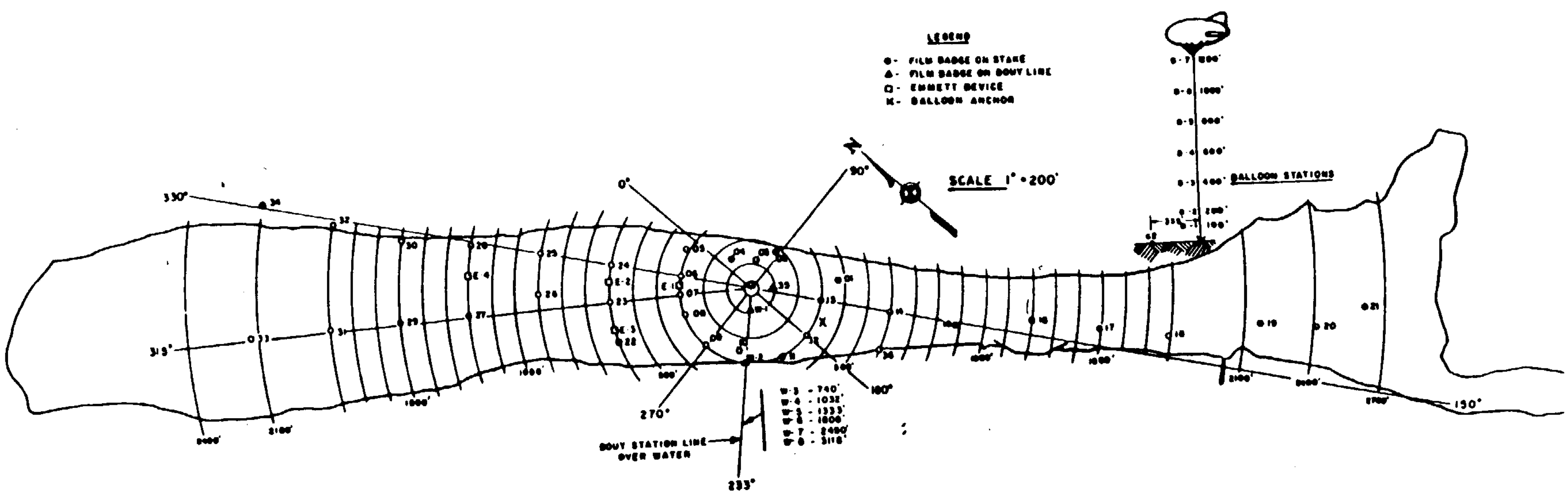

Figure 1 Location of film-badge stations.

Shots Quince and Fig using facilities of Edgerton, Germeshausen and Grier, Inc., (EG&G) at the Eniwetok Proving Ground.

Following recovery, film badges were shipped to the U.S. Army Signal Research and Development Laboratory (ASRDL) for development and interpretation of film density into dose units.

NTS Operations: Film Dosimetry. Shot Hamilton was detonated in Frenchman Flat. Stations were placed as follows: (1) four Emmett devices at distances of 100, 200, 400, and 800 yards

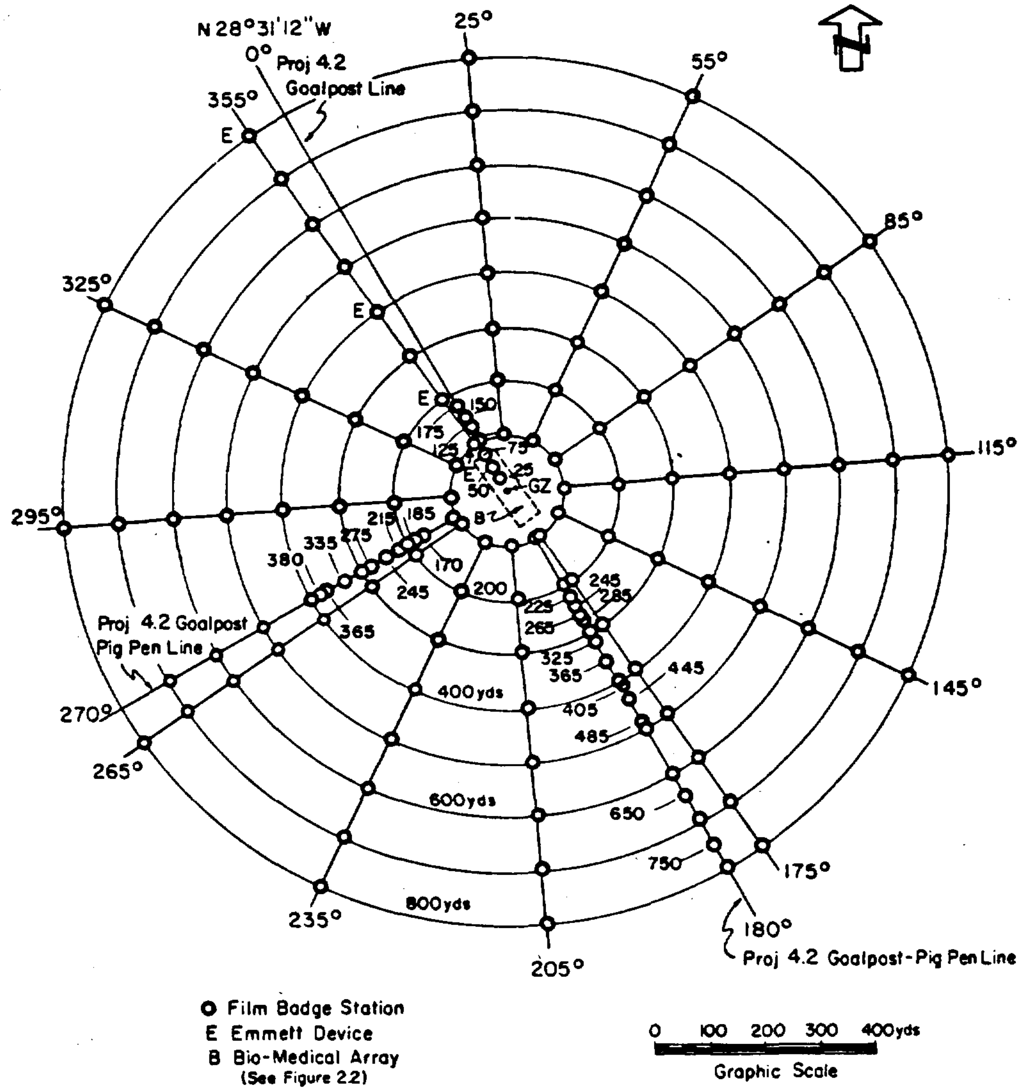

Figure 2 Station layout, Shot Hamilton.

on the 355-degree azimuth; (2) 96 film-badge stakes and alpha-monitoring pads on a polar grid with twelve lines spaced 30 degrees apart and stations spaced at 100-yard intervals from 100 to 800 yards, and (3) 147 film badges for the biomedical station array.

The station plot plan for the polar grid, Emmett stations, and biomedical free-field film-badge locations is shown in Figure 2. The biomedical foxhole-and-vehicle array is shown in Figure 3. All stations, except those in foxholes and vehicles, were mounted on quick-recovery racks ("goal posts") or fastened to pig-pen fences and had a line of sight to ground zero.

Film dosimeters were installed several days before the shot and removed at H+24 hours.

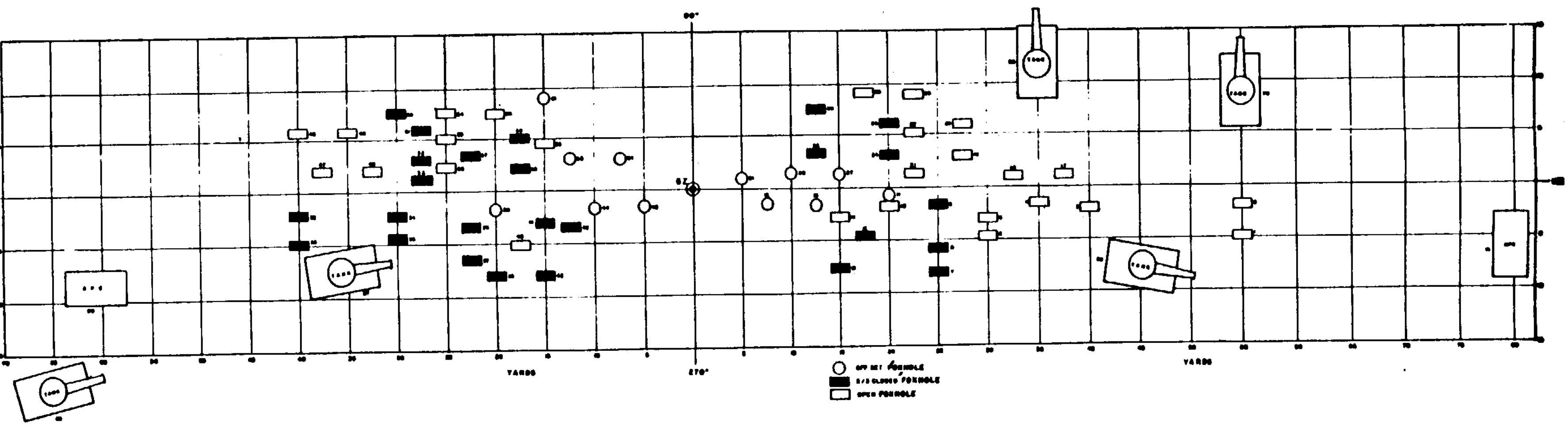

Figure 3 Biomedical foxhole-and-vehicle array.

Calibration of film commenced immediately following the shot, using facilities of EG&G at Las Vegas, Nevada. Film badges were sent to ASRDL, Fort Monmouth, New Jersey, for developing and interpretation of film density into dose units.

Shot Humboldt was planned for the same ground zero as that of Shot Hamilton. The Emmett devices and stake stations in Frenchman Flat were instrumented. However, on D−1, Shot Humboldt was moved to Area 3; the project participation, therefore, was severely limited. Project 2.12b provided Project 4.2 with 28 film badges, the locations of which are shown in Figure 4. The film dosimeters were installed by Projects 2.12a and 4.2 several hours before the shot and recovered during early-entry postshot operations of these projects. Calibration, processing and read-out were accomplished in the same manner as for Shot Hamilton.

NTS Operations: Field Surveys. Personnel of the U. S. Army Chemical Corps Training Command, Fort McClellan, Alabama, performed gamma field surveys to (1) delineate the 10

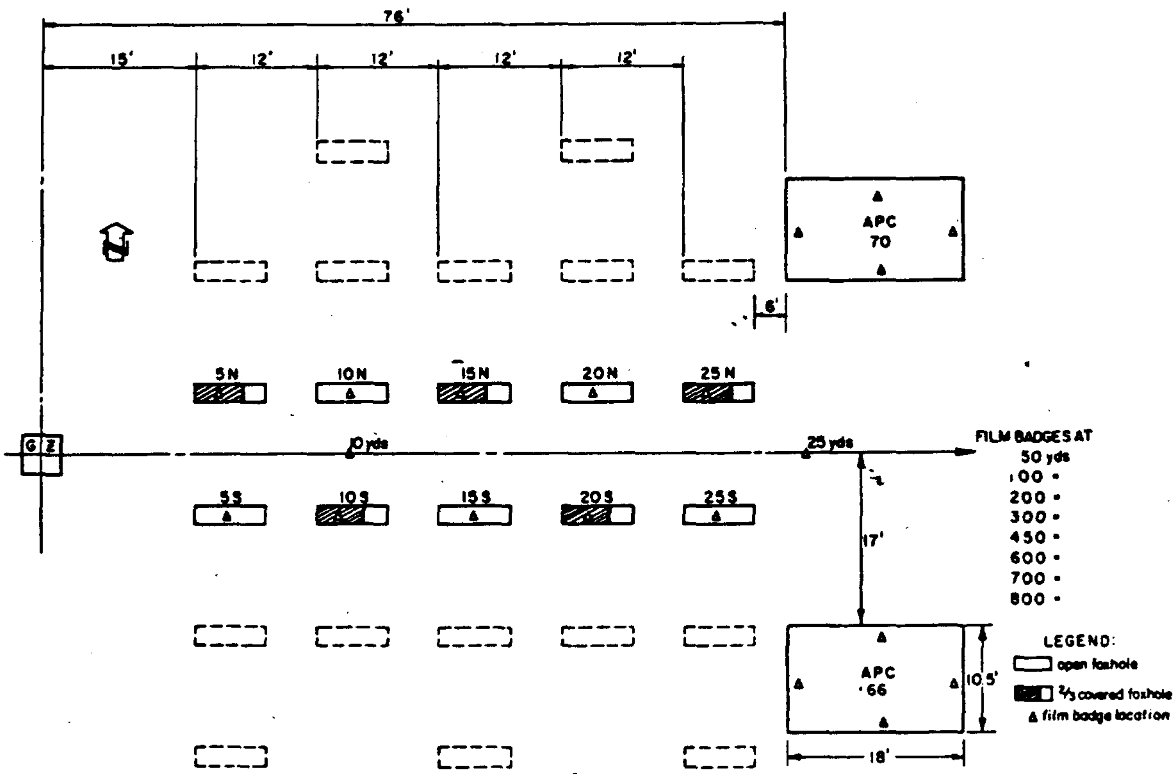

Figure 4 Station layout, Shot Humboldt.

r/hr contour at H + 15 minutes, (2) to detect any isolated 10 r/hr hot spots at H + 15 minutes, and (3) to determine field decay rates.

Immediately following the passage of the blast wave from Shot Hamilton, four two-man monitoring teams moved into the area by jeep from the forward manned station. One team surveyed the general outlying area around ground zero with special reference to the ground in the direction of observed cloud travel. The other three teams began immediate surveys on four each of the twelve film-badge stake lines. These teams recorded the location of the 10 r/hr point on each stake line by dropping markers and then measuring the dose rate at each stake outside of the 10 r/hr line. This procedure was repeated on subsequent surveys, readings also being taken at each point where 10 r/hr had been noted previously.

For Shot Humboldt, the late shifting of ground zero from Frenchman Flat to Area 3 necessitated some changes. Time was available only to install four lines of stakes, one in each major compass direction, at 200-yard intervals to 800 yards.

Immediately following the passage of the blast wave, one team moved into the area, marked the 10 r/hr point on the east line, and measured the dose rate at each stake on that line outside of this point. At 15 minutes following the shot (H + 15 minutes), four additional teams made similar surveys on all four lines and the other team made a general survey as for Shot Hamilton. Additional surveys were made up to H + 6.5 hours when the area was evacuated for another shot.

A survey for alpha contamination was made after Hamilton D + 1 day at the 96 alpha-monitoring pads adjacent to the film-badge stake stations. Operational conditions, such as late shifting of ground zero and time limitations before and after the shot, precluded any alpha surveys for Shot Humboldt.

INSTRUMENTATION

Incremental-Gamma-Dose Recorders. The incremental-gamma-dose recorder used was a modified Emmett device as employed by Project 2.5 during Operation Plumbbob. This device is essentially a conveyor belt of film badges, each of which is exposed in turn from an underground shield and returned thereto. A typical station cross-section is shown in Figure 5, and a line drawing of the mechanism is presented as Figure 6. A complete description of the Emmett device is given in Reference 3.

Since the Emmett device does not have a fast-enough time resolution to differentiate the various initial gamma pulses from very-low-yield bursts, it was decided to change the traveling speed of the film badges in order that each badge would be exposed for 1 minute. (The device so modified ran for 20 minutes and could provide fallout-arrival data or early-decay data.) By spacing the film badges so that some were in the probe above ground at zero time, it was possible to obtain total gamma doses during the first 3, 15, and 30 seconds.

The speed of the Emmett device, as modified by this project, was sensitive to battery voltage. Consequently, freshly charged batteries were employed, and the speed was set by adjusting a resistance in series with the motor just before the assembly was lowered into the ground. The speed setting was verified by timing the drive-sprocket revolutions with a stop watch. Dry runs over the entire cycle of operation showed that the speed did not vary by more than ±5 percent.

Figures 7, 8, and 9 are photographs of steps in the installation of an Emmett station. In Figure 7, the instrument rack complete with film probe is lowered into the underground shield. In Figure 8, the rack and probe are in place along with sand-bag shielding. The top of the probe was screwed in place after the 30-second-exposure film badges were checked for proper position at the top of the probe. Figure 9 shows the completely installed station, with the blast shield in place and the timing wire connected. (The smaller cylindrical tube was originally used during Operation Plumbbob to protect an ionization chamber. It was not used by this project.)

Film-Badge Station. The film badges were placed in National Bureau of Standards (NBS) holders, which were inserted, in turn, in plastic cigarette cases for dust and moisture protection. A discussion of the NBS holder is contained in Reference 9. All film badges within 300 yards from ground zero were also placed inside of electrical "condulets" or pipe nipples for blast, missile, and thermal protection.

A condulet is a small, weather-proof, iron, electrical-junction box. The model used by this project incorporated female pipe threads to facilitate fastening to iron-pipe stakes. (The condulets were previously treated to remove cadmium plating and so minimize neutron-capture photons.)

The film packs were mounted on top of 3-foot-long pipes driven into the ground. For Shot Hamilton, several stations were extended to 6 feet elevation to clear a shadow-shielded area behind a dike to the east of ground zero. Figure 10 illustrates a typical station.

Table 3 lists the ranges covered by the individual films in the film badge.

Field-Survey Instrumentation. The field-survey teams used the AN-PDR/39 for gamma readings and the Eberline PAC-3G alpha survey instrument for alpha readings. These instruments are described in References 11 and 4 respectively.

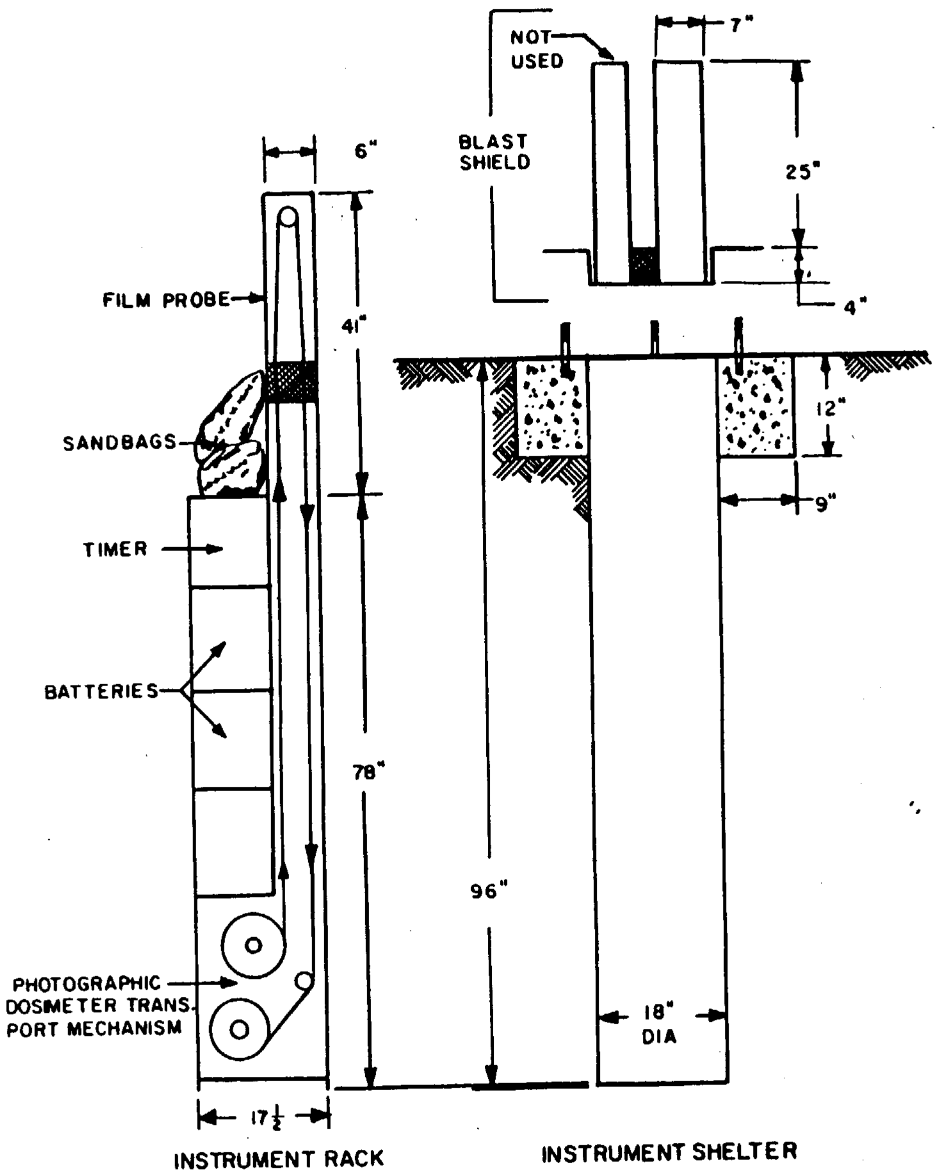

Figure 5 Cross section of Emmett device.

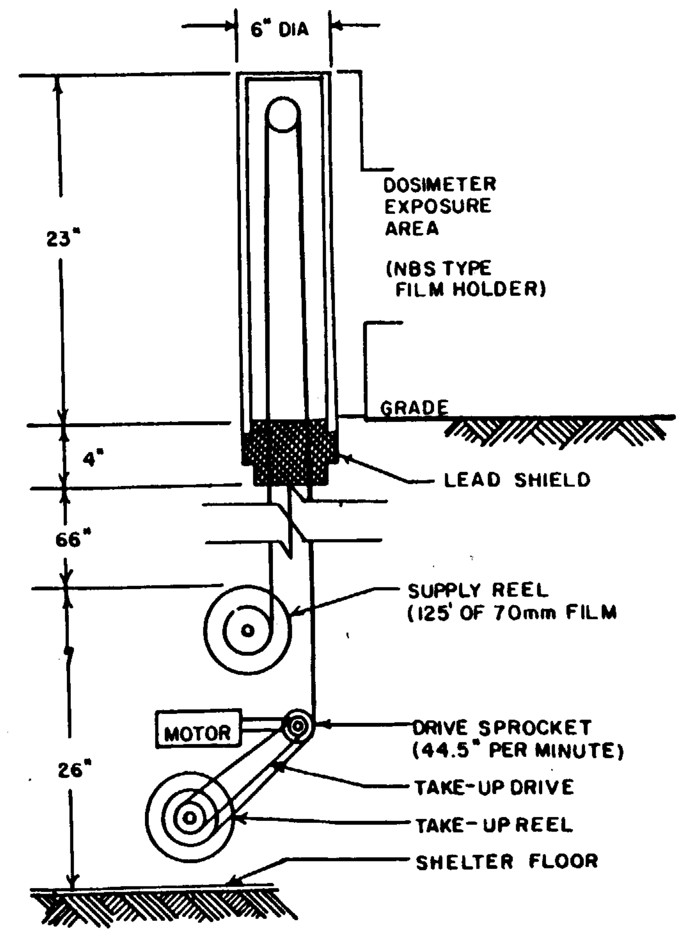

Figure 6 Emmett device mechanism.

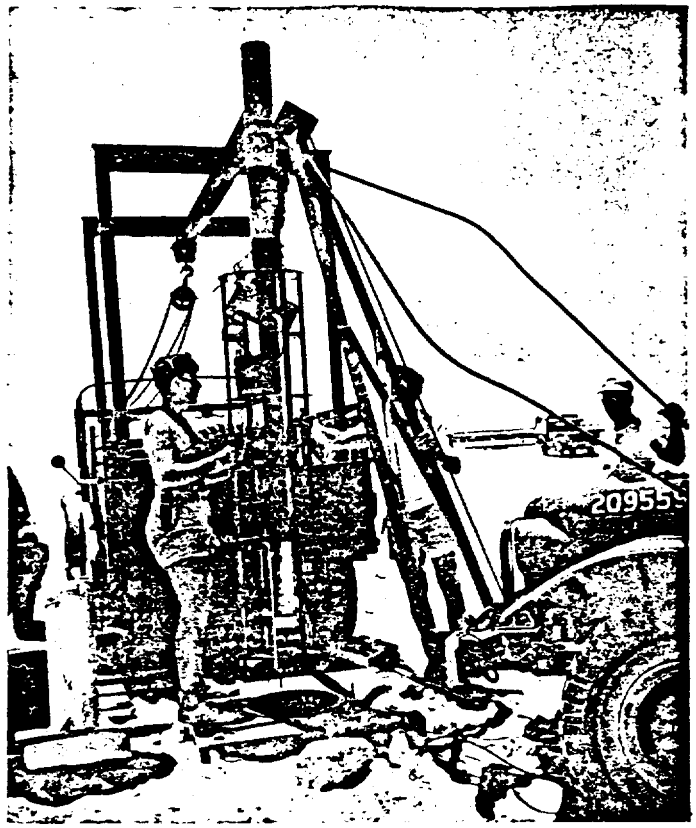

Figure 7 Installation of Emmett device.

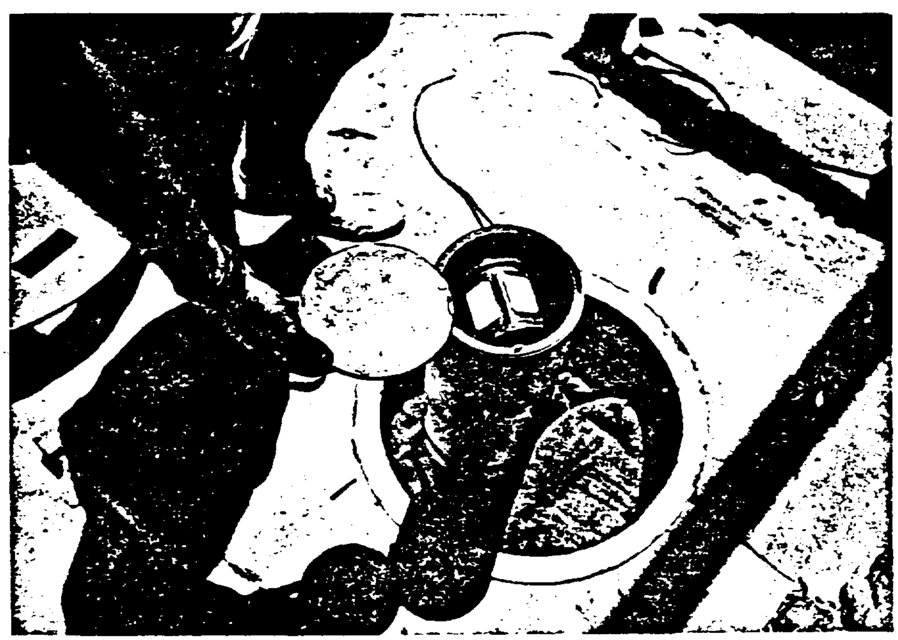

Figure 8 Closeup of Emmett device during final installation.

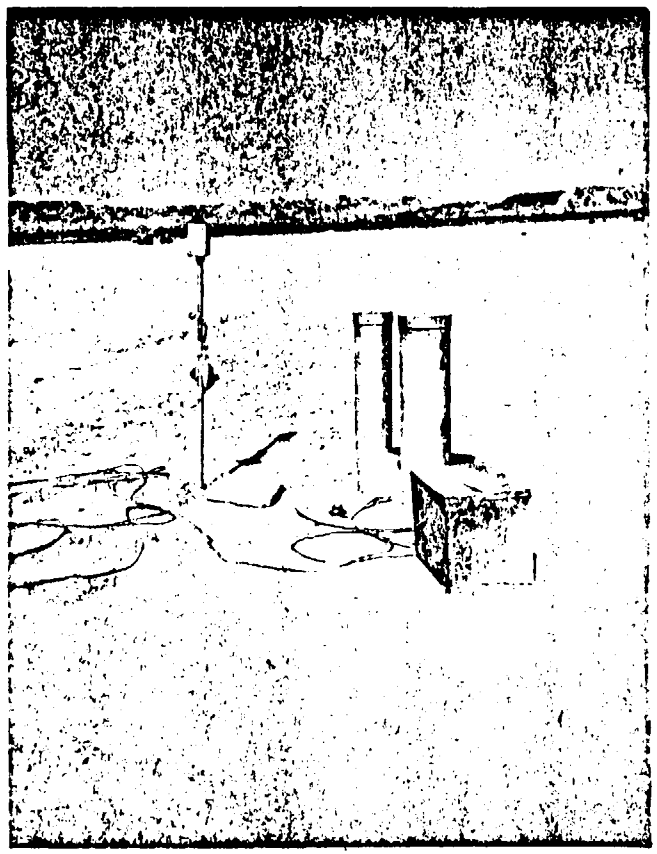

Figure 9 Emmett device as installed.

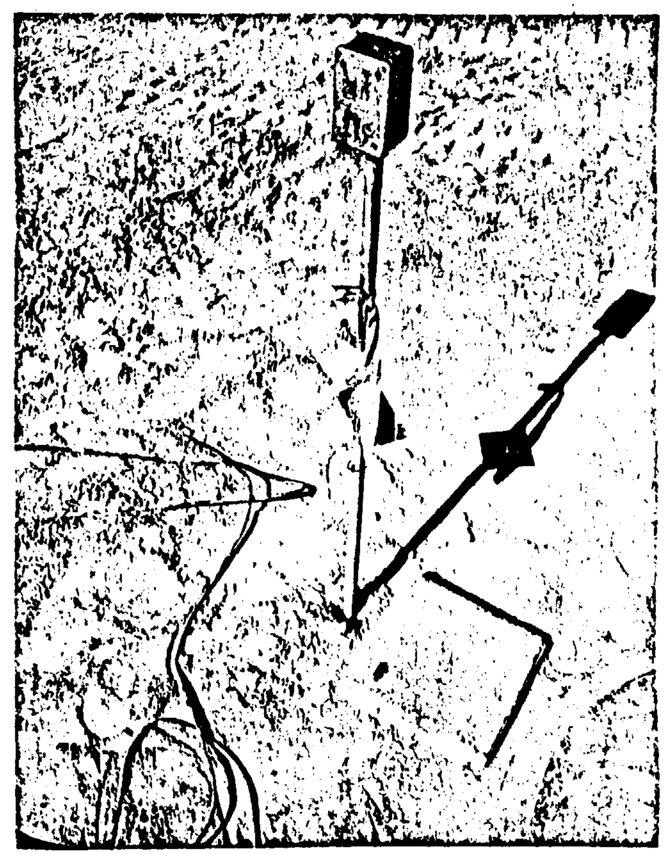

Figure 10 Film-badge station.

DATA REQUIREMENTS

To accomplish project objectives, initial gamma measurements were required versus distance from ground zero for each of three fractional-kiloton detonations. It was necessary that the extent and magnitude of residual-gamma fields be known so that data corrections could be made. Residual-gamma readings were obtained from the early field surveys of Projects 2.10 and 2.12b and the Emmett devices of Project 2.9.

Total gamma doses were measured with film badges. The film dosimetry used had an accuracy of ±20 percent, not considering residual radiation, station shielding, and neutron effects

TABLE 3 SENSITIVITY RANGES OF DOSIMETRY FILM

Packet Type	Emulsion	Range
	number	r
DuPont 553	502	0.3 to 5
DuPont 553	510	3 to 50
DuPont 553	606	25 to 2,500
Eastman Special Order	548-0 DC	2,500 to 50,000

on the film (Reference 9). It has been estimated that these effects, if uncorrected, could reduce the accuracy of the film dosimetry to ±50 percent (Reference 9).

Film emulsions are sensitive to capture-gamma photons and to thermal and fast neutrons. The capture-gamma photons are generated by thermal neutrons absorbed in the walls of the film-protection container. Table 4 lists data from Reference 5 on the film sensitivity to neutrons.

The subject of neutron-capture photons generated in a steel shield has been treated in Reference 10. For this steel, the capture photons can be estimated from the following equation:

TABLE 4 NEUTRON SENSITIVITY OF FILM

Packet Type	Emulsion	Low-Energy (Gold) Neutrons	High-Energy Neutron Dose
	number	10^{-9}(n/cm^2)/r	n rep dose/r
DuPont 553	606	3.4 ± 1.8	28 ± 17
DuPont 553	502	3.2 ± 1.7	26 ± 15
DuPont 553	510	2.3 ± 1.4	19 ± 12
Eastman Special Order	548-0 DC	4.7 ± 1.9	20 ± 12

$$P = \frac{2 K n\sigma I^0_{th}}{\mu - N\Sigma}\left(e^{-N\Sigma x} - e^{-\mu x}\right) \qquad (2)$$

Where:
- P = generated dose, in roentgens
- K = conversion factor from gamma flux to gamma dose, 2.39×10^9 r/(photon/cm^2)
- x = thickness of shield, cm
- $n\sigma$ = macroscopic activation cross section,per cm
- μ = linear absorption coefficient, per cm
- $N\Sigma$ = macroscopic removal cross section, per cm
- I^0_{th} = incident thermal neutron flux, neutrons/cm^2

The neutron effects all increase the indicated dose as read on the films; whereas absorption of gamma rays by the shield decreases the indicated dose, resulting in some self-cancellation of effects.

RESULTS

Project 2.9 participated in Shots Quince and Fig, which were surface detonations of fractional-kiloton nuclear devices on Site Yvonne at EPG. Project 2.12b participated in Shots Hamilton and Humboldt, which were tower detonations of similar devices at the Nevada Test Site.

Shot Quince.

Shot Hamilton. Participation was successful in Shot Hamilton, a 1.17-ton shot on a 50-foot wooden tower. All Emmett devices functioned properly and all film-badge stations were recovered.

Film calibration, station recovery, field surveying, and film processing proceeded according to plan. The same calibration source used for Shot Fig was available for this event. However, an accident during film development resulted in the loss of data from the project film-badge stake station and Emmett devices. A defective safe light in the dark room fogged the films to the extent that interpretation of density was impossible. However, all open-field stations of Project 4.2 in three directions were instrumented by Project 2.12b. Each of the stations had a direct line of sight to ground zero and provided enough data points to meet the objective of documenting initial gamma dose versus distance.

All open-field data were corrected the same as for Shot Fig and appear in Figure 11. The doses in vehicles, open foxholes, and some offset foxholes were corrected for neutron and

station-shielding effects. However, most offset foxholes and all $^{2}/_{3}$-covered foxholes were not adequately instrumented for neutron measurements, and the data had to be left in the raw form.

Gamma dose versus distance, corrected to a relative air density of 0.9, is tabulated in Table 5 and plotted in Figure 12. Gamma doses at all Project 4.2 stations are tabulated in Table 7 for the test-condition relative air density of 0.83. Alpha-survey data is tabulated in Table 8.

The 10 r/hr isodose lines as determined from field surveys were irregular star-shaped curves inclosing very small areas as shown in Table 9. No evidence of a downwind highly radioactive (hot) line was found. The minimum and maximum distances of these curves from ground zero at various times are tabulated in Table 9. The gamma decay followed the usual fission-product decay law with an average exponent of −1.1 from H+10 minutes to H+1 day. Reference 13, the report of the field-survey group, contains a multitude of data sheets, curves, and isodose plots of the data.

Shot Humboldt. Participation was successful in Shot Humboldt, a 7.8-ton shot on a 25-foot wooden tower. Since this event was moved at the last minute to a different ground zero than planned, effort was limited to instrumenting Project 4.2 stations with film badges plus a few hasty gamma-field surveys.

The film badges were recovered within a few minutes after detonation by a coordinated effort of this project and Projects 2.12a and 4.2. Instrumentation, and the two APC vehicles, were dragged out of the ground-zero area by pulling cables.

The open-field data were corrected the same as for Shot Fig. See Figure 11. The doses in vehicles and foxholes were corrected for neutron and station-shielding effects.

Gamma dose versus distance, corrected to a relative air density of 0.9, is tabulated in Table 5 and plotted in Figure 12. Gamma doses at all Project 4.2 stations are tabulated in Table 10 for the test-condition relative air density of 0.85.

The 10 r/hr isodose lines, as determined from field surveys, were roughly circular with radii of 200 yards or less. There was no evidence of a downwind hot line. The minimum and maximum distances that these curves extended from ground zero at various times are tabulated in Table 9. Since field surveying had to be concluded by H+7 hours, only limited experimental data was obtained on field decay. These data only suggest that the contamination decayed according to the fission-product law. Reference 13 contains all survey data obtained for this event.

DISCUSSION

Although the film badges were in all cases exposed for more than 1 minute, it is felt that the data in Figure 12 represents initial gamma dose or a combination of initial dose and dose caused by the passage of the low cloud. Some close-in stations for all three events were affected by

TABLE 6 EMMETT GAMMA DOSES

Time Interval	Dose at Station			
	100 yd, 325 deg	200 yd, 325 deg	200 yd, 305 deg	400 yd, 325 deg
min	r	r	r	r
0 to 0.05	3,200	390	360	19
0 to 0.25	3,500	280	390	79
0 to ½	4,100	700	260	54
0 to 1	2,700	450	*	11
½ to 1½	580	89	110	0
1 to 2	120	5.8	5.3	0
1½ to 2½	14	0	1.8	0
2 to 3	3.8	0	0	0
2½ to 3½	3.6	0	0	0
3 to 4	1.3	0	0	0
3½ to 4½	2.9	0	0	0
4 to 5	1.5	0	0	0
4½ to 5½	1.4	0	0	0
5 to 6	0	0	0	0

* Defective film badge

residual fields.

the Hamilton and Humboldt low air bursts, the values beyond 100 yards approximated straight lines. The best least-squares fit for these lines was calculated and extrapolated to 100 and 1,000 yards.

the open-field results of Shots Hamilton and Humboldt were adjusted to a 1-ton yield for comparative purposes. Predicted gamma doses were calculated from Equation 1 for a 1-ton yield. Gamma doses scaled from 1-kt curves in TM 23-200 (Reference 12) to a 1-ton yield agreed with these calculations.

All open-field test results (adjusted to 1-ton yield) were divided by the predicted 1-ton yield (calculated and scaled) data for each 100-yard distance from detonation, and plotted as a function of distance in Figure 13. From the curves in this figure, it is possible to note trends in the variation of test results from predictions.

The doses from the low air bursts were higher than predicted surface-burst values by a factor of two for close-in distances (100 to 300 yards). This is in keeping with the theory that initial dose from a surface burst is reduced by 50 percent compared to an equivalent air burst. Many

basic references (such as References 7 and 12) indicate that surface and near-surface bursts produce the same initial gamma dose. Figure 13 shows that the low air-burst doses do approach the surface-burst doses at distances in excess of 1,000 yards. This phenomenon would favor the use of a low air burst rather than a surface burst for tactical employment, as there would be a bonus in the higher target dose. Figure 12 illustrates this bonus quite well. The 7.8-ton low air burst (Shot Humboldt) delivered as much gamma dose within 400 yards of ground zero,

Lethal doses (600 r) were received at approximately 150 yards from detonation

The delivery crews, in the open, would receive only 15 r or less of initial gamma radiation at a range of 600 yards.

For the case of an air burst and a surface burst having the same yield, it can be seen from Figure 13 that at distances within 300 yards from detonation, the air burst delivered at least

TABLE 7 SHOT HAMILTON GAMMA DOSES AT PROJECT 4.2 STATIONS

Relative air density = 0.83

Station	Slant Distance	Corrected Dose	Uncorrected Dose
	yd	r	r
Doses in the Open, South Line			
100 S	101.3	350	
200S	200	67	
I	225	49	
II	245	39	
III	265	32	
IV	285	26	
300 S	300	22	
VI	325	18	
VIII	365	12	
400 S	400	9.4	
X	405	9.0	
XII	445	6.7	
XIV	485	5.0	
500 S	500	4.5	
XV	505	4.3	
600 S	600	2.3	
600 Pen	600	2.3	
650 S	650	1.7	
650 Pen	650	1.7	
700 S	700	1.3	
700 Pen	700	1.3	
750 S	750	0.96	
750 Pen	750	0.96	
800 S	800	0.73	
800 Pen	800	0.73	
Doses in the Open, West Line			
100 W	101.3	350	
I	170	101	
II	185	82	
200 W	200	67	
III	200	67	
IV	215	55	
VI	245	39	
VIII	275	28	
300 W	300	22	
X	305	21	
XII	335	16	
XIV	365	12	
XV	380	11	
400 W	400	9.4	
500 W	500	4.5	
600 W	600	2.3	
700 W	700	1.3	
Doses in the Open, North Line			
25 N	30.2	~1,800	
50 N	52.8	1,700	
75 N	76.9	540	
100 N	101.3	350	
125 N	126	210	
150 N	150	140	
175 N	175	94	
Doses in Vehicles			
T 67 NW	39.6	430	
APC 66 NW	62.9	715	
T 65 NW	70.1	300	
T 68 SE	40.8	720	
T 69 SW	48.7	370	
T 70 SE	58.4	500	
APC 71 SW	82.0	390	
Doses in Open Foxholes			
14 SW	22.9	~2,300	
62 NE	23.0	~1,800	
40 NW	24.9	1,750	
26 SE	25.6	1,800	
58 NE	27.3	1,050	
22 SE	28.7	710	
10 SW	26.4	*	
23 SE	29.4	410	
21 SE	28.3	*	

TABLE 7 CONTINUED

Station	Slant Distance	Corrected Dose	Uncorrected Dose
	yd	r	r
54 NE	31.2	460	
55 NE	30.6	420	
56 NE	30.3	460	
19 SE	32.4	220	
20 SE	32.9	680	
5 SW	34.8	160	
6 SW	34.6	240	
18 SE	36.7	570	
49 NE	36.8	230	
48 NE	39.4	340	
4 SW	39.0	300	
17 SE	41.1	350	
47 NE	41.2	290	
46 NE	43.9	430	
3 SW	43.5	430	
1 SW	57.8	280	
2 SW	57.7	290	
Doses in Offset Foxholes			
64 NE	18.8	69	
30 SE	19.8	68	
63 NE	21.3	*	
27 SE	22.8	16	
Uncorrected Doses in Offset Foxholes			
45 NW	17.7		200
16 SW	18.7		70
44 NW	19.8		*
61 NE	24.4		130
38 NW	26.4		60
11 SW	26.3		54
31 SE	17.6		*
15 SW	21.2		*

Station	Slant Distance	Corrected Dose	Uncorrected Dose
	yd	r	r
Uncorrected Doses in Two-thirds Covered Foxholes			
29 SE	22.4		750
28 SE	21.3		900
43 NW	21.3		900
41 NW	22.9		1,100
42 NW	24.0		640
13 SW	23.9		530
59 NE	24.9		680
60 NE	24.5		590
12 SW	24.7		590
39 NW	27.3		*
24 SE	26.4		530
25 SE	26.9		470
36 NW	28.4		530
37 NW	29.1		500
57 NE	28.4		*
7 SW	31.3		400
8 SW	30.8		460
9 SW	30.3		420
51 NE	32.8		480
52 NE	32.4		450
53 NE	32.2		480
34 NW	34.6		400
35 NW	34.7		450
50 NE	35.3		390
32 NW	43.5		230
33 NW	43.7		240

* These film badges were either lost or grossly inconsistent.

twice the dose of the surface burst. At greater distances this dose differential decreased until the doses became very nearly equal at 1,000 yards.

The residual fields in the Hamilton and Humboldt ground-zero areas were much lower than expected as the yields of these devices were much lower than expected. In both cases the contamination was apparently fission products from contaminated tower materials. No elongated fallout pattern was observed although one survey team for each event hunted downwind fallout. The alpha-contamination levels of Shot Hamilton, at 100 yards or more from ground zero, were below 120 $\mu g/m^2$ which is considered an insignificant hazard. The Hamilton ground-zero area

TABLE 8 SHOT HAMILTON ALPHA-CONTAMINATION LEVELS, $\mu g/m^2$

Slant Distance	Alpha Contamination at Azimuths Shown, deg											
	25	55	85	115	145	175	205	235	265	295	325	355
yd												
100	62.4	116.6	15.0	2.2	1.8	1.9	72.4	2.6	23.0	24.0	27.4	66.7
200	20.5	112.0	1.6	0.5	0.8	0.9	0.9	6.5	19.5	0.4	0.9	0.7
300	2.4	91.4	1.4	0.4	0.02	0	0	1.6	2.9	1.8	1.6	1.6
400	0.9	30.9	0.5	0	—	—	0	1.9	3.6	1.0	1.1	0.5
500	2.4	29.2	0.4	—	—	—	0	2.5	3.8	1.1	1.1	0.9
600	1.5	9.1	—	—	—	—	0.3	3.8	7.9	0.5	0.6	0.6
700	1.3	1.4	—	—	—	—	0	2.1	2.6	—	0.9	0.6
800	1.7	4.1	—	—	—	—	0	1.4	3.1	—	—	—

was visually observed to be strewn with tower debris, paraffin, etc. Since this debris probably became embedded with fission products and alpha emitters, the absence of this debris (as would be the case for a detonation in free air) would cause even lower ground-zero contamination levels.

Since the Emmett devices were not in the fallout area for Shot Fig, no data were obtained on fallout arrival or decay. The activity detected for a few minutes at the closest stations was probably crater shine.

CONCLUSIONS

The following conclusions are based on the results from Shots Hamilton, and Humboldt

TABLE 9 DISTANCE FROM GROUND ZERO TO 10 R/HR ISODOSE LINES, SHOTS HAMILTON AND HUMBOLDT

Time After Detonation	Shot Hamilton		Shot Humboldt	
	Minimum	Maximum	Minimum	Maximum
min	yd	yd	yd	yd
10	40	90	140	205
15	30	75	120	180
30	15	65	85	150
60	5	55	30	100

and apply to fractional-kiloton-yield devices tested.

1. Initial gamma doses in the 300- to 900-yard range may be extrapolated from TM 23-200 data with confidence for surface bursts.

2. For the same yield at distances up to 300 yards from detonation, an air burst will deliver at least twice the initial gamma dose of a surface burst. At greater distances the difference between the doses received from the air burst and the surface burst decreases, and the doses become nearly equal at 1,000 yards.

3. Lethal doses (600 r) of initial gamma radiation are received at approximately 150 yards from the point of detonation a 7.8-ton low air burst

(Shot Humboldt), while the delivery crews, in the open, would receive 15 r of initial gamma radiation at ranges of 575 yards, respectively.

4. The observed variation of gamma dose with azimuth for the surface burst is probably caused by the contribution of dose from the transient cloud.

5. The residual-gamma fields produced by low air bursts detonated on wooden towers are very small (less than 200 yards radius at H+15 minutes) for the 10 r/hr isodose line. This field is due to fission-product radiation, probably from contaminated tower materials.

TABLE 10 SHOT HUMBOLDT GAMMA DOSES AT PROJECT 4.2 STATION (TEST CONDITIONS)

Station	Slant Distance	Corrected Dose
	yd	r
Doses in the Open, East Line		
25	26.4	19,000
50	50.7	5,500
100	100	2,800
200	200	500
300	300	160
450	450	41
600	600	14
700	700	7.5
800	800	4.1
Doses in Foxholes		
5 S	10.5	14,500
10 N	13.3	16,000
15 S	16.9	*
20 N	20.1	6,000
25 S	23.7	5,900
5 N	10.5	13,600
10 S	13.3	13,200
15 N	16.9	3,900
20 S	20.1	6,400
25 N	23.7	1,500
Doses in Vehicles		
APC 66	30.5	
Front		19,000
Middle		11,500
Middle		9,800
Rear		10,000
APC 70	30.5	
Front		18,200
Middle		13,200
Middle		12,200
Rear		10,400

* Film badge defective.

6. The alpha-contamination levels from low air bursts at distances greater than 100 yards are considered to be an insignificant hazard.

RECOMMENDATIONS

Further experimentation on fractional-kiloton devices is desirable because the small number of tests performed were accomplished under far-from-ideal testing conditions.

1. The initial gamma radiation from a surface burst should be measured over a 2π area instead of over small, narrow sectors, and should include dose-versus-time measurements.

2. The above measurements should be repeated for air bursts, using balloons instead of wooden towers for support of the device, in order to avoid interference from the residual radioactivity caused by tower material.

3. Laboratory experiments should be performed to determine more accurately the effects of neutrons on film emulsions and the contribution of the gamma photons from thermal-neutron capture in the walls of the protective shields.

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