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Project 2.1
Gamma Exposure Versus Distance

May-July 1956

Pacific Proving Grounds

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FOREWORD

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

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

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ABSTRACT

The objective of Project 2.1 was to determine gamma exposures versus distance from the point of detonation of various high-yield devices.

The following types of dosimeters were used as gamma-radiation detectors: photographic, quartz-fiber, chemical, and phosphate-glass. Correction factors were applied to compensate for the nonlinear spectral response of the dosimeters, when necessary, and for station shielding. All detectors were calibrated with Co^{60} sources. Photographic dosimeter readings were accepted as the most reliable on a statistical basis and were used as bases for most of the curves plotted. Photographic dosimeter film-badge service and Co^{60} calibration facilities were provided to other projects as requested.

Initial-gamma radiation was measured at a series of stations located at about 1 to 4 miles from ground zero. Mechanisms were installed at some of these stations to shield the detectors from residual radiation. An analysis of the data indicates that the initial-gamma exposure at 3 miles from Cherokee, Zuni, and Navajo was about 1 r. Consequently, initial-gamma radiation was of little military significance to exposed personnel as compared to thermal and blast damage resulting from high-yield devices.

The curves in this report vary from those published in TM 23-200 (Reference 1). The field data falls below predictions at longer ranges and is greater than predicted at shorter ranges. This difference between predicted and field data increases with increasing yield.

For fallout residual-gamma radiation measurements, instrument stations were located on almost every island of Bikini Atoll at distances where neutron-induced activity was entirely negligible. The amount of residual-radiation exposure was a function of the fission yield. Residual-gamma radiation data points are mapped in this report for Shots Zuni, Flathead, Navajo, and Tewa.

FOREWORD

This report presents the final results of one of the projects participating in the military-effect programs of Operation Redwing. Overall information about this and the other military-effect projects can be obtained from WT-1344, 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) discussion of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.

PREFACE

Acknowledgement is made to Captains Edwin York and Roger Boyd who attended this operation as Project 2.1 personnel through the cooperation of the Air Forces Special Weapons Center (AFSWC). Their assistance and suggestions contributed to the success of this project.

Appreciation is expressed for the cooperation and participation of the Department of Radiobiology, School of Aviation Medicine, USAF, and particularly for the chemical dosimeter data, evaluated in the field and laboratory, of 1st Lt. Sanford C. Sigoloff, who also contributed the material for the discussion of chemical dosimeters in Section 2.2.3.

Acknowledgment is also made to: Doctors Dunham, Corsbie, and Buterhoff, for making available the AEC dosimeter systems described herein; Doctors Taplin and Cassen, University of California, for their production and evaluation of the AEC dosimeter systems; S.C. Rainey, of Project 2.72, for providing DT-60 phosphate-glass dosimeters and 200r gamma-range quartz-fiber dosimeters; C.N. Kingery, of Project 1.1, for making available the use of the 113 series of stations on Sites Charlie and Dog for Shots Cherokee and Tewa; and Majors Roy Weidler and Thomas Connolly, of Headquarters, Armed Forces Special Weapons Project (AFSWP), for technical suggestions and advice.

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Chapter 1
INTRODUCTION

1.1 OBJECTIVE

The objective of Project 2.1 was to determine gamma exposures versus distance from the point of detonation of various high-yield devices. A secondary objective was to determine the gamma exposures received in several discrete time intervals between time of arrival of the thermal pulse and 1 minute after time of detonation.

1.2 BACKGROUND

Initial-gamma radiation may be considered as that emitted during the first 30 seconds after detonation. The initial-gamma radiation output for nuclear devices with yields up to 250 kt has been well documented in previous test operations [redacted] Gamma-radiation measurements from high-yield nuclear devices during Operation Ivy showed that the initial-gamma radiation did not follow the same scaling laws that had been established for smaller devices [redacted] This was attributed in part to the hydrodynamic effect, which results in an enhancement of the gamma radiation. This effect is caused by the passage of the shock front through the detector station, resulting in a reduced air density between detector and radiating source. Section 1.3.4 gives a simplified treatment of the hydrodynamic effect.

Measurements were made during Operation Castle by the U.S. Army Signal Engineering Laboratories to determine the empirical relation between yield and hydrodynamic enhancement [redacted] Some high-yield Operation Castle devices provided data points; however, it was felt that additional data were needed at a number of suitably spaced points for various yields and types of nuclear devices to determine more valid scaling laws. The present scaling laws for initial-gamma radiation from high-yield thermonuclear devices were based on data from relatively low-yield fission devices (1 to 500 kt), a few data points from Operation Ivy, and the sparse data from Operation Castle. Initial-gamma radiation appeared to be of little significance compared to damage caused by blast and thermal effects.

Residual-gamma radiation is here defined as that which reaches the detector 30 seconds or more after time of detonation. Residual-gamma exposure measurements have been made by various organizations at previous test operations (References 2, 3, 5, and 6). During Operation Buster-Jangle, the Signal Corps, in conjunction with the National Bureau of Standards (NBS), made residual-gamma exposure measurements of a 1-kt surface blast and a 1-kt device detonated at a depth of 17 feet (Reference 7). During Operation Teapot the U.S. Army Signal Engineering Laboratories made measurements of residual-gamma exposure resulting from an underground blast of a low-yield device (Reference 3).

The advent of high-yield thermonuclear devices has resulted in a manifold increase in the radiological hazard, and gamma radiation from fallout has become of greater military significance. Operation Castle demonstrated that large quantities of radioactive material could be deposited by high-yield devices over areas of several thousand square miles. This led to a military requirement for fallout data for devices of various types and yields. Project 2.1 was charged with documenting the residual-gamma radiation exposures from the fallout at land stations at Bikini Atoll during Operation Redwing.

1.3 THEORY

The gamma radiation emitted from a nuclear detonation may be divided into two portions: initial radiation and residual radiation. The residual radiation may include radiation both from fallout and neutron-induced activity. In this report, the radiation emitted during the first 30 seconds is termed initial radiation, and that received after 30 seconds is called residual radiation.

1.3.1 Initial-Gamma Radiation. For a fission-type device the initial radiations are divided approximately as shown in Table 1.1 (from Reference 8). The major contributions to initial-gamma radiation are from the fission-product gammas and from the neutron-capture gammas resulting from the N^{14} (n, γ) N^{15} reaction between device neutrons and atmospheric nitrogen. The prompt gammas are nearly all absorbed in the device itself and are of little significance

TABLE 1.1 ENERGY PARTITION IN FISSION

Reference 8

Mechanism	Percent of Total Fission Energy	Total Energy per Fission
	pct	Mev
Kinetic Energy of Fission Fragments	81	162
Prompt Neutrons	4	8
Prompt Gammas*	4	8
Fission-Product Gammas	2.7	5.4
Fission-Product Betas	2.7	5.4
Fission-Product Neutrinos	5.5	11
Delayed Neutrons	0.1	0.2
Totals	100.0	200.0

* Mostly absorbed in the device

outside the device. The fission-product gammas predominate at close distances (Reference 8). The N^{14} (n, γ) N^{15} gammas become increasingly important at greater distances and eventually become the major contributor. This applies only to devices with yields of less than 100 kt, in which the hydrodynamic effect is small. Figure 1.1 shows the contribution from fission-product gammas and N^{14} (n, γ) N^{15} for a 1-kt surface burst. Therefore, the fission products become a more important source of initial-gamma exposure from high-yield fission-fusion devices at greater distances.

For thermonuclear devices, in addition to gamma radiation from fission-product gammas, it is necessary to consider the interaction of neutrons from the fusion process with N^{14}. The radiation caused by the fusion process may vary over wide limits, depending on the design of the device. For a given yield, the number of neutrons available may be 10 times as great for fusion as for fission, and therefore a large number of gamma photons are contributed by the N^{14} (n, γ) N^{15} reactions (Reference 9). However, because of the short half life, this gamma radiation decays before it can be enhanced by the hydrodynamic effect. Gammas from the longer-lived fission products are greatly enhanced by this effect. Therefore, fission products are the most important source of initial-gamma exposure resulting from high-yield fission-fusion devices. The preceding discussion is also in essential agreement with the expanded treatment given in Reference 10.

1.3.2 Residual-Gamma Radiation. Residual-gamma radiation consists of fission-product radiation from fallout and radiation from neutron-induced activity. The decay rate of the resid-

ual radiation from fallout will follow approximately the expressions:

$$I_t = I_1 t^{-1.2} \tag{1.1}$$

and

$$r = \int_{t_1}^{t_2} I_t \, dt = 5I_1 (t_1^{-0.2} - t_2^{-0.2})$$

Where: I_t = exposure rate at time t

I_1 = exposure rate at unit time

t = time

r = exposure between times t_1 and t_2, where $t \geq 10$ seconds.

It is expected that the decay of the residual radiation will vary with device design. For example, the presence of Np^{239} would tend to decrease the absolute value of the decay exponent for a period of time.

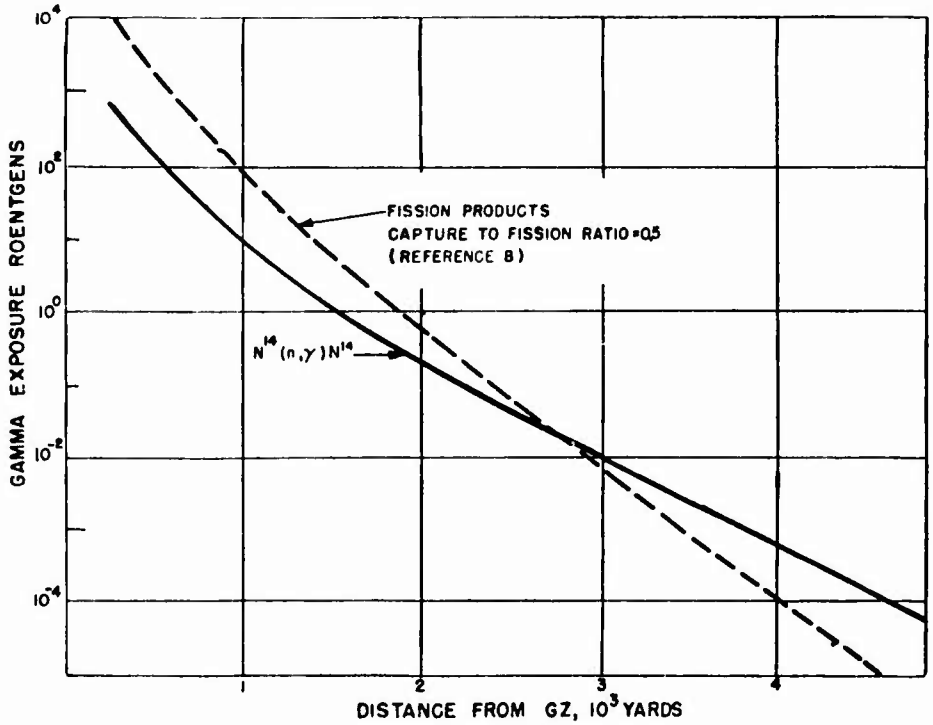

Figure 1.1 Gamma exposure for 1 kt surface burst.

1.3.3 Absorption in Air. The absorption of unscattered gamma radiation in air is exponential with distance. From a point source of mono-energetic radiation, the variation of intensity with distance is expressed as:

$$I_D = \frac{I_0 e^{-\mu D}}{4\pi D^2} \tag{1.2}$$

Where: I_D = intensity at distance D

I_0 = source intensity

μ = linear absorption coefficient (this varies with gamma energy, and is generally lower for higher energies).

D = distance

The absorption coefficient μ in Equation 1.2 is applicable for narrow-beam geometry, and a correction should be made for field conditions where the detector is approximately a 2π sensing element. This is done by adding a buildup factor B to Equation 1.2, to account for the scattered radiation that will be detected. Buildup factors for different energies and distances have been calculated (Reference 11), and some values are shown in Table 1.2. For omni-directional detectors, the expression is:

$$I_D = \frac{I_0 B e^{-\mu D}}{4\pi D^2} \tag{1.3}$$

1.3.4 Hydrodynamic Effect. As shown in Section 1.3.3, the attenuation of gamma radiation is highly dependent on the amount of absorber between the source and the detector. For devices of

TABLE 1.2 CALCULATED BUILDUP FACTORS

The buildup factor B given here is the factor B_r ($\mu_0 D$, E_0) as computed by Nuclear Development Associates for AFSWP (Reference 9).

Energy (E_0) Mev	B		
	1,000 yds	1,500 yds	3,000 yds
1	16.2	29.3	85.0
3	3.85	5.35	10.2
4	2.97	4.00	7.00
10	1.70	2.01	2.90

less than 100-kt yield, essentially all the initial-gamma radiation is emitted before the shock front can produce an appreciable change in the effective absorption of the air between source and detector. For high-yield devices, the velocity of the shock front is sufficiently high to produce a strong enhancement of a large percentage of the initial-gamma radiation (Reference 10). The higher the yield, the larger is this percentage. A simplified treatment of the hydrodynamic effect follows.

Assume a sphere that has a volume V_0 and radius R, and is filled with a gas of density ρ_0 and mass M. Then,

$$M = V_0 \rho_0 = \frac{4\pi R^3 \rho_0}{3} \tag{1.4}$$

Let the gas be compressed into a shell with thickness ΔR (R remaining constant). The new gas volume is expressed as V_1 with a density of ρ_1 ($V_1 = 4\pi R^2 \Delta R$). The mass has not changed; thus

$$M = V_0 \rho_0 \doteq 4\pi R^2 \Delta R \rho_1 \, (\Delta R << R)$$

$$\frac{4\pi R^3 \rho_0}{3} \doteq 4\pi R^2 \Delta R \rho_1 \tag{1.5}$$

$$\Delta R \rho_1 \doteq \frac{R\rho_0}{3} \tag{1.6}$$

Equation 1.6 indicates that a ray originating in the center of the sphere would traverse only $\frac{1}{3}$ of the mass in the shell model that it would in the homogeneous model. The result would be an enhancement of radiation. Once the shell of material in the shock front passes the detector, an even greater enhancement results.

As previously stated, the N^{14} (n, γ) N^{15} component of initial radiation is essentially emitted within 0.2 second. Since it takes at least 1 second for the shock front to reach a detector at a distance of 7,000 feet (even for devices in the order of 6 Mt), the N^{14} (n, γ) N^{15} component is not significantly enhanced. The fission-product gammas continue to contribute for the first 30 seconds. Therefore, this radiation is strongly enhanced by the shock wave.

Chapter 2
PROCEDURE

2.1 OPERATIONS

Project 2.1 participated in Shots Cherokee, Zuni, Flathead, Dakota (limited), Navajo, and Tewa. For every shot except Dakota, all possible stations were instrumented with every available type of detector of appropriate range. For Shot Dakota, stations were loaded with photographic-type dosimeters just prior to shot time, and these were recovered at the instrumentation time for Shot Navajo. Stations were instrumented as late as possible prior to shot time and recovered as soon as rad-safe conditions permitted.

2.2 INSTRUMENTATION

2.2.1 Photographic Dosimeter. The primary detector consisted of film exposed in the NBS-type film holder. This consisted of a bakelite container with an 8.25-mm wall thickness covered with a 1.07-mm layer of tin and a 0.3-mm layer of lead. The lead and tin acted as filters to suppress the lower energies sufficiently to keep the response linear above 115 kev. Below 115 kev, the gamma radiation was attenuated excessively, and exposure caused by gammas below 115 kev was small compared to that above 115 kev (Reference 12). The thickness of bakelite was determined experimentally on the assumption that the spectrum from a 10-Mev betatron was similar to the initial radiation of the device (Reference 13). The electron equilibrium layer presented a source of electrons that might have been scattered into the emulsion to replace those electrons produced by gamma radiation absorbed near the surface of the film and lost without being detected. In the energy range from 115 kev to 10 Mev, the dosimeter was considered accurate to within ±20 percent with the film types used on this operation (References 14 and 15).

For Shot Cherokee, film was exposed both with and without NBS holders to obtain an indication of the presence of low gamma-energy components in initial radiation, since bare films showed maximum sensitivity to gamma energies at about 60 kev.

Two dental-size film packets, each containing from one to three different film emulsions, could be placed in the holder. A lead strip of 0.78-mm thickness was wrapped around the outer edge of the holder to cover the seam. The holder was placed in a sealed plastic can to protect the film from weather while in the field.

The primary film packets used were Du Pont 553 containing Emulsions 502, 510, and 606, and an Eastman packet containing a special microfilm (SO 1112) and spectroscopic-type 548-0 double-coat film. These packets were individually sealed in polyethylene bags. In addition, Eastman spectroscopic-type 548-0 single-coat was used when very-high exposures were anticipated. Table 2.1 lists the ranges of the films, and Figures 2.1, 2.2, and 2.3 show examples of the calibration curves.

The films were stored in a refrigerator at Site Elmer and withdrawn as needed. Sets of calibration films were exposed to the Co^{60} calibration source from 30 minutes to 12 hours after each detonation. Films were processed about a week after each event, thereby minimizing possible errors caused by latent image fading. Variations caused by temperature, aging, and processing technique were compensated for by the calibration film. Factors that caused variation in density from event to event were the latent image fading of Eastman 548-0 film and the small variation in the temperature of the developer solution. In Shots Dakota, Navajo, and Tewa, an increase in the background density equivalent to about 200 mr was noted on the Dupont Emulsion 502. The use of calibration film in each of these events compensated for this background density increase.

The photographic transmission density was read on an Ansco-McBeth Model 12 densitometer, with a calibrated photographic density wedge used as a standard. Exposures were determined by comparing densities of the field films with the density-versus-exposure curves for each film emulsion calibrated on the Co^{60} source.

TABLE 2.1 EXPOSURE RANGES OF THE EMULSIONS

Emulsion Type		Range
		r
Du Pont	502	0.05 to 10
	510	1.0 to 100
	606	10.0 to 3,000
Eastman	SO1112	50.0 to 2,500
	548-0 de	3,000 to 100,000
	548-0 se	5,000 to 100,000

2.2.2 Quartz-Fiber Dosimeters. Seven ranges of quartz-fiber dosimeters, similar to the IM-93/UD evaluated by Teapot Project 6.1.1, were used (References 16 and 17). These dosimeters had an accuracy of ± 10 percent of true dose for Co^{60} gamma rays. The quartz-fiber dosimeters suffered serious errors because of rate dependence at rates higher than 10^5 r/hr; however, data from the instruments used did not exhibit these errors since such rates were avoided. These dosimeters were calibrated with the Co^{60} source and a correction was made on all readings. All quartz-fiber dosimeters were continually checked for excessive leakage (> 2 percent of full scale per day), and those showing excessive leakage were replaced. Table 2.2 lists the manufacturer's numbers and ranges. Project 2.72 supplied 30 dosimeters with a range of 0 to 200 r.

2.2.3 Chemical Dosimeters. Chemical dosimeters furnished by the Air Force, Atomic Energy Commission, and University of California at Los Angeles were of three main types, all based on the same principle; to wit, acid formed from the irradiation of a chlorinated hydrocarbon is a linear function of radiation exposure throughout a broad range (25 to 100,000 r) (References 6, 18, 19, 20 and 21). These dosimeters had an accuracy of about 10 percent.

All dosimeters were of the direct-reading type, accomplished by observation of color changes in the indicator dye. The color change in most instances was from red (pH 6.0 or above) to yellow (pH 5.6 or below). Since the color transition of the indicator dye was a function of exposure, the exposure doses could be estimated by color comparison with irradiated controls.

TABLE 2.2 QUARTZ-FIBER-DOSIMETER RANGES

Bendix No.	Range
	r
608	0 to 10
622	0 to 20
610 (IM-20/PD)	0 to 50
613	0 to 100
680 (IM-93/UD)	0 to 600
803	0 to 2,000
(IM-107)	0 to 200

Evaluation of overexposures (pH 5.6 or below) was determined by the titration of the acid formed per ml of chlorinated hydrocarbon with standardized 10^{-3} Normal NaOH. The amount of

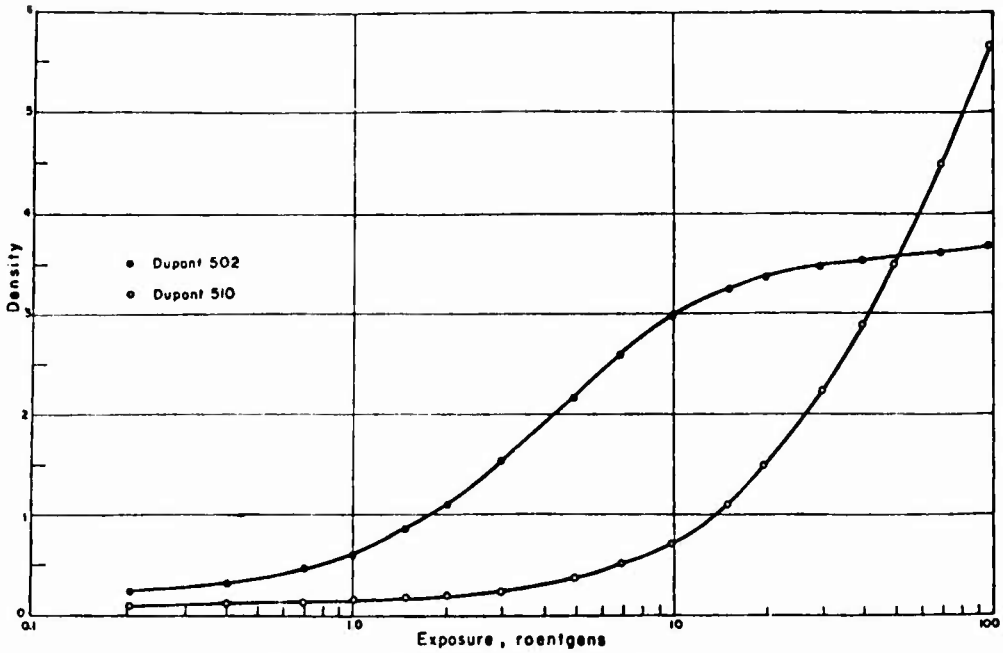

Figure 2.1 Co^{60} calibration curves for film types.
(Film in NBS holder.)

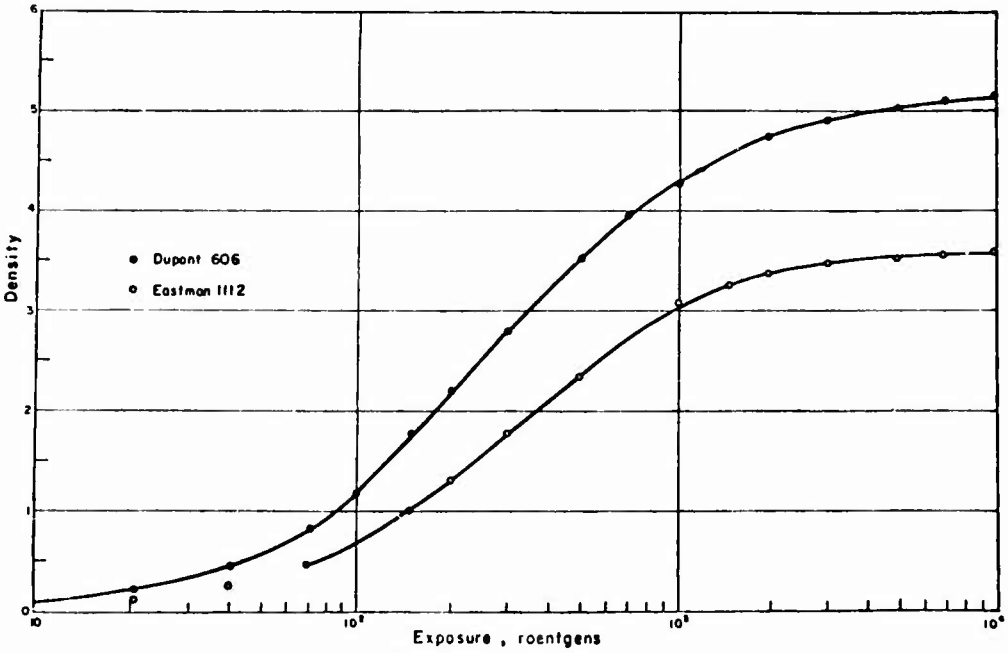

Figure 2.2 Co^{60} calibration curves for film types.
(Film in NBS holder.)

base required to return the overlaying acidimetric dye to its preirradiation pH value was a measure of the acid produced by the absorbed dose. Use of predetermined data for the system in respect to sensitivity to Co^{60} gamma radiation (namely the milliequivalents of acid produced per ml of chlorinated hydrocarbon per r absorbed) and division of these values into the acid produced by the unknown exposure yielded the gamma doses in r. The Air Force dosimeters from Shots Cherokee and Zuni were read in the field by 1st Lt. S. C. Sigoloff, USAF, of Project 4.1. The remainder of the dosimeters were forwarded to the United States for reading and evaluation by the furnishing agency.

2.2.4 Radiac Detector DT-60/PD: Project 2.72 supplied 175 DT-60's, which were exposed to Shots Flathead and Navajo. Those exposed to less than 600 r were read on site, while the ones exposed to larger doses were read and evaluated at the Naval Medical Research Institute.

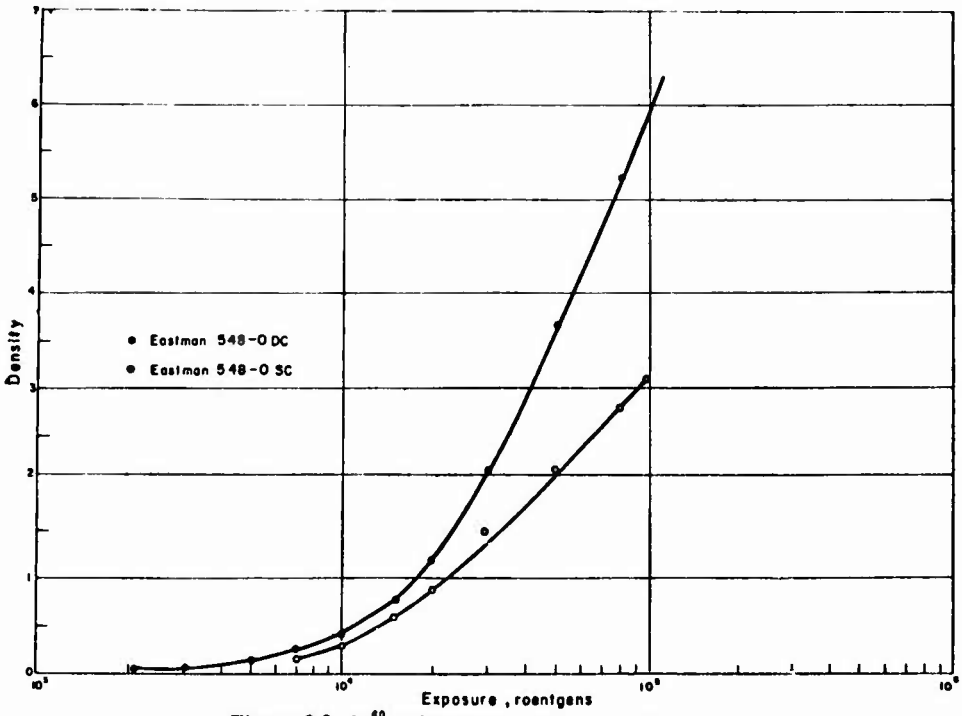

Figure 2.3 Co^{60} calibration curves for film types.
(Film in NBS holder.)

These dosimeters have an accuracy of about 20 percent. (A technical description and an evaluation of this instrument is found in References 16, 17, 22, and 23.)

2.2.5 Radiac Set AN/PDR-39. These instruments, calibrated with Co^{60}, were used to measure the exposure rate in fields of residual-gamma radiation whenever these fields would affect the data. The AN/PDR-39 was a military standard, field-type, portable instrument used for detecting and measuring gamma-exposure rates (Reference 24). Evaluation of the T1B (AN/PDR-39) in WT-1138 (Operation Teapot Project 6.1.2) applied primarily to earlier-time residual fields (up to H + 50 hours). Since Operation Redwing Project 2.1 used these instruments in residual fields at H + 80 to H + 100 hours, the errors noted in WT-1138 would be somewhat smaller. The AN/PDR-39 had an accuracy of about 20 percent.

2.2.6 Quartz-Fiber Device (Rate Device) for Exposure Versus Time. This device incorporated eight quartz-fiber dosimeters connected to a battery of zeroing potential. The dosimeters

were activated by removal of the battery potential from the dosimeters during various intervals of the first minute after the detonation. The dosimeters recorded the radiation that arrived after they were activated.

The devices were mounted vertically in a plastic and aluminum frame (Figures 2.4 and 2.5). A spring-loaded solenoid was below each dosimeter, mounted so that it depressed the charging pin at the base of the quartz-fiber dosimeter. A battery charged the dosimeters to zero reading. Upon activation, a Hayden chronometric motor programmed the operation. The latching solenoids were activated in intervals of about 2 seconds, varying with position and event. The charging potential was removed from the dosimeters, thus the dosimeters integrated the exposure that arrived after the activation time.

Several dosimeters were included to read the total exposure. One dosimeter was activated at 58 seconds after the detonation to give an estimate of the effects of residual radiation. At 60 seconds, a solenoid-release mechanism caused the entire instrument to drop down the 8-inch steel-pipe stations to 6 feet below the surface. Thus, the instruments were shielded from most of the residual radiation.

The device was housed in an aluminum canister 32 inches high and 7-½ inches in diameter, with a 0.10-inch wall thickness. The battery pack that powered the mechanism was in the bottom half of the canister. A 6-inch space at the top of the canister was utilized for the placement of various other dosimeters, and Project 2.51 gold and sulphur neutron detectors for Shots Zuni and Cherokee. The instrument was activated when an eutectic element was melted by thermal radiation. The eutectic element consisted of two pieces of 0.008-inch brass shim stock, plated black with Ebanol C, and soldered with Cerrolow 136, an eutectic that melts at 136 F. The total activation delay from time of detonation was estimated at ½ second.

2.2.7 Mechanical Drop Mechanism. A mechanical drop mechanism was installed in the pipe caps of some of the 4-inch and 8-inch steel-pipe stations. These stations were instrumented with five sets of dosimeters. Three sets were suspended in the top of the station and fell to the bottom when activated. The first set of dosimeters was suspended by a black nylon string extending from an arm attached to the cap top through a hole in the cap. The gamma data indicated that the string burned through in about ½ second after the detonation. A second set of dosimeters was suspended by a wire from a piece of angle iron on top of the cap. The shock front activated this group. A third set of dosimeters was suspended from a mechanical 60-second photographic timer. The timer was activated when the thermal radiation burned through a piece of black nylon string. The instruments dropped approximately 1 minute after the detonation. In addition, one set of dosimeters remained fixed at the top and another at the bottom of the station.

The dosimeters were affixed in this fashion to afford an opportunity to measure the radiation up to the time of activation and then be dropped to the bottom of the pipe for shielding from residual radiation. Thus, the dosimeters integrated the dose received up to the time of arrival of thermal and shock pulses, the dose received up to 1 minute, ant total radiation.

2.2.8 Station Layout, Utilization, and Construction. The station layout and utilization are given in Table 2.3. The station construction is shown in Table 2.4, since the amount of shielding surrounding the detector was of importance in the data analysis.

Series 210 stations consisted of an 18-inch open-end aluminum cylinder mounted 36 inches above the ground on a 2-inch-diameter aluminum rod. The dosimeters were retained by a bolt at each end of the cylinder.

Series 210, 211, 212, and 213 stations were constructed of steel pipe capped at both ends. The pipes were mounted vertically in the ground with the exception of Series 212, where the pipes were mounted vertically in the center of a 6-foot concrete cube, the surface of which was flush with the ground.

Series 113 stations were located on the coral reef east of Site Charlie and were constructed of steel pipe. These stations were primarily for use by Project 1.1 but were utilized by Project 2.1 for Shots Cherokee and Tewa.

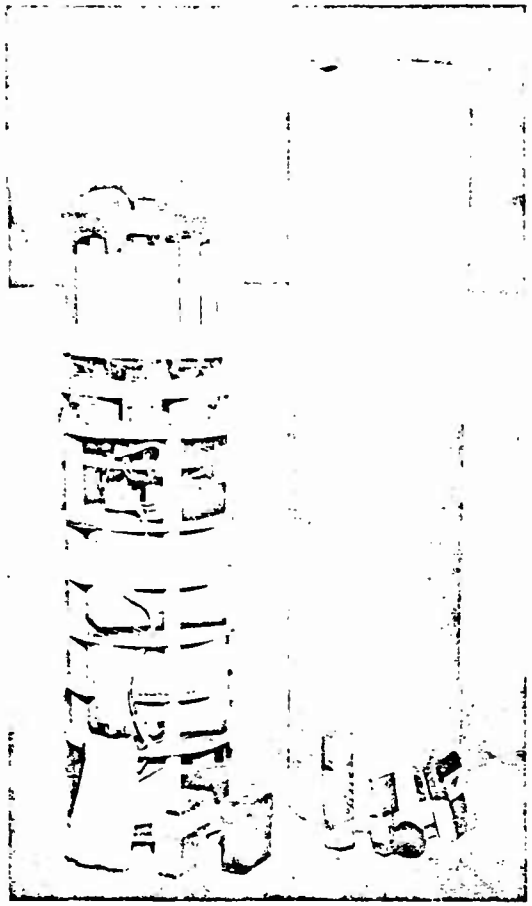

Figure 2.4 Quartz fiber rate device with dosimeters.

Figure 2.5 Quartz fiber rate device with dropping mechanism.

TABLE 2.3 STATION LAYOUT AND UTILIZATION

CODE: A - Film Badges
B - Quartz Fiber
C - Chemical
D - Phosphate Glass
E - Quartz Fiber Rate Versus Time
F - Mechanical Dropping Device

Station Number	Location	Shot Cherokee	Shot Zuni	Shot Flathead	Shot Dakota	Shot Navajo	Shot Tewa
212.01	Able	ABCE	ABC	ABD	—	ABCD	ABC
212.02	Charlie	ABCF	ABC	ABD	—	ABCD	ABC
212.03	Dog	ABC	ABC	ACDF	A	ABDF	ABC
212.04	Easy	ABC	AB	ABCDE	A	ABCD	ABC
212.05	Fox	ABC	AB	ABCDF	—	ABCDE	ABC
212.06	George	ABC	ABC	ABCD	—	ABCD	ABC
211.01	Dog	—	—	ABCDE	A	ABCDE	—
211.02	Dog-Easy	—	—	ABCDE	A	ABCDE	—
211.03	Easy-Fox	—	—	ABCDE	—	ABCDE	—
211.04	Fox-George	—	—	ABCD	—	ABCDF	—
213.01	Man Made 3	—	—	ADF	AD	ADF	—
213.02	Dog	—	—	ADF	—	ADF	—
213.03	Dog-Easy	—	—	ADF	—	ADF	—
213.04	Fox	—	—	ADF	—	ADF	—
210.19	Fox	—	—	—	—	A	—
210.20	George	—	—	—	—	A	—
210.22	Oboe Reef	—	AC	—	—	—	—
210.23	Oboe	ABC	AC	ABCD	—	ABCD	ABC
210.24	Oboe Reef	—	AC	—	—	—	—
210.25	Oboe Reef	—	AC	—	—	—	—
210.26	Peter Reef	—	AC	—	—	—	—
210.27	Peter	ABC	AC	ABCD	—	ABCD	ABC
210.29	Roger Reef	—	AC	—	—	—	—
210.30	Roger	ABC	AC	ABCD	—	ABCD	ABC
210.31	Roger Reef	—	AC	—	—	—	—
210.32	Uncle Reef	—	AC	—	—	—	—
210.33	Uncle Reef	—	AC	—	—	—	—
210.34	Uncle	ABC	AC	ABCD	—	ABCD	ABC
210.35	Uncle Reef	—	AC	—	—	—	—
210.37	William	ABC	ABC	ABCD	—	ABCD	ABC
210.38	Yoke	ABC	ABC	ABCD	—	ABCD	ABC
210.39	Zebra	ABC	ABC	ABCD	—	ABCD	ABC
210.40	Alfa	ABC	ABC	ABCD	—	ABCD	ABC
210.41	Bravo	ABC	ABC	ABCD	—	ABCD	ABC
210.56	Peter Reef	—	AC	—	—	—	—
210.23'	Oboe	—	ABCF	—	—	—	—
210.27'	Peter	—	ABCE	—	—	—	—
210.30'	Roger	—	ABCE	—	—	—	—
210.34'	Uncle	—	ABCE	—	—	—	—
112.01	Charlie	A	—	—	—	—	ABC
113.01	Charlie-Dog	A	—	—	—	—	ABC
113.02	Charlie-Dog	AB	—	—	—	—	ABC
113.03	Charlie-Dog	AB	—	—	—	—	ABC
113.04	Charlie-Dog	AB	—	—	—	—	AC
113.05	Charlie-Dog	AB	—	—	—	—	AC
113.06	Charlie-Dog	AB	—	—	—	—	—
113.07	Man Made 1	—	—	—	—	ABD	ABC
113.08	Man Made 2	—	—	—	—	ABD	ABC
113.09	Man Made 3	—	—	—	—	ABD	ABC
250.01	Charlie	A	—	—	—	—	—
250.02	Charlie	A	—	—	—	—	—
250.03	Charlie	A	—	—	—	—	—
251.01	Charlie-Dog	AB	—	—	—	—	—

2.2.9 Co^{60} Field Calibration. Exposures were made with a well calibrated 4 π, 200-curie Co^{60} source that had an effective energy of 1.2 Mev. The source consisted of two cylindrical Co^{60} pellets with a total height of 1.58 inches and a diameter of 0.39 inch. The pellets were gold plated and sealed in two concentric monel capsules. The source capsule was stored in a lead pig and was forced up a monel metal tube by compressed air for use. The total thickness of the monel capsules and tube was 0.33 inch. Instruments were exposed on a horizontal wooden platform 3 inches below the level of the raised source and 2 feet above the lead pig.

The source was calibrated on site using Victoreen r-chambers that had 5-mm lucite caps. These chambers were calibrated at NBS for use at 22C and 760 mm of pressure. Corrections for pressure and temperature differences were applied to chamber readings at the time of calibration. Corrections for decay of the source were applied to calibration curves after the calibration was completed.

A 200-curie Co^{60} calibration curve for exposure rate versus distance is shown in Figure 2.6. Calibrations for Shots Lacrosse and Cherokee were made using an 80-curie Co^{60} source of similar design used as a collimated source (Reference 3). This source was discarded after Shot Cherokee because of capsule rupture.

TABLE 2.4 STATION CONSTRUCTION

Station Series	Material	Diameter	Wall Thickness	Height Above Surface	Depth Below Surface
		inch	inch	ft	ft
210.0	Aluminum	3	0.25	3	—
210.27' 210.30' 211.0 212.0	Steel	8	0.45	2.5	6
210.23' 210.34'	Steel	8	0.45	2	1
213.0	Steel	4	0.30	4	4
113.0	Steel	3	0.25	5	—

2.3 DATA REQUIREMENTS

To accomplish Project 2.1 objectives, gamma-radiation measurements were required at surveyed distances from ground zero for each of six high-yield thermonuclear devices detonated at Bikini Atoll. It was necessary that these measurements should permit discrimination between initial- and residual-gamma radiation so that a true measure of initial-gamma radiation could be made.

Measurements of the residual-gamma exposure rate and decay rate were required at known times for stations instrumented in a contaminated field, and after all shots to allow extrapolation of residual-exposure measurements to times other than recovery time. For those stations at which initial-gamma data were recorded, residual-field gamma exposure rate measurements were required to allow for correction of the initial data to account for the effect of the residual-gamma field.

The initial exposure values are accurate to within 30 percent. This figure is based on an overall 20-percent accuracy of the NBS dosimeter for initial-gamma measurements in the energy range from 115 kev to 10 Mev and in the exposure range from 1 to 50,000 r (Reference 3). The variations in wall thickness and other possible station-shielding errors in shielding corrections amounted to about 15 percent. The error in mutual shielding effects among the instruments as

they were positioned amounted to approximately 10 percent based upon measured results, and the error in converting film dosimeter readings to quartz-fiber response is about 10 percent. These errors combined to about 30 percent for overall accuracy. In individual cases where the residual-gamma contamination was proportionately larger, the accuracy may be reduced, particularly in those cases where the residual-gamma contamination was estimated. These cases are discussed individually as they appear. The photographic and quartz-fiber dosimeter readings are generally recommended as being most reliable on a statistical basis, since they were put out in large numbers and in many ranges at each station location. Statistical variation for these individual detectors was within 10 percent.

The residual-exposure values, after correction for shielding effects and energy response, should be accurate to within 50 percent. This accuracy is based primarily on variations in the individual dosimeters due to response characteristics and station shielding effects. The variance of a particular type of dosimeter at a given location was 15 percent.

2.3.1 Initial Exposure Calibration. The radiation spectrum of a 10-Mev betatron (3.5-Mev effective average energy) is believed to approximate the initial spectrum of a nuclear detonation. To normalize exposure readings from a film dosimeter based on Co^{60} calibrations to the energy

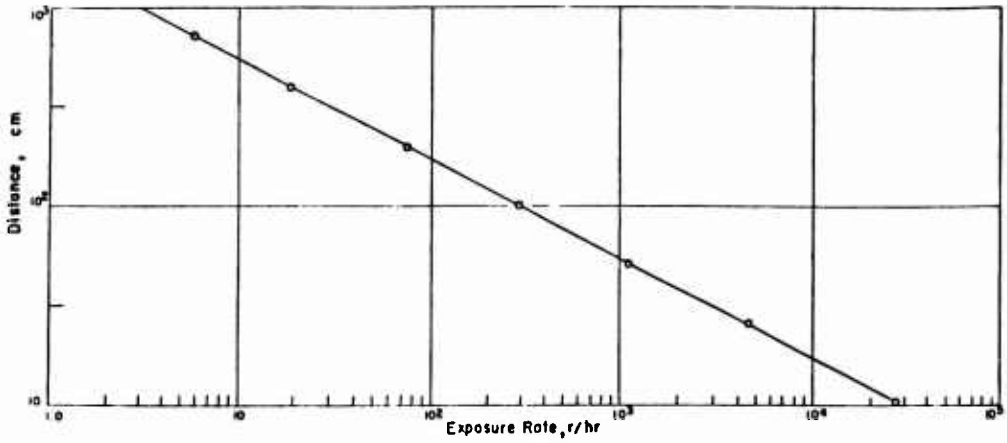

Figure 2.6 200 curie Co^{60} calibration curve.

of this betatron, field exposure values are multiplied by a normalization factor. To obtain such normalization factors, NBS has exposed photographic dosimeters to Co^{60} and to the Naval Ordnance Laboratory (NOL) 10-Mev betatron on several occasions in the past 5 years (References 2, 3, 4, 15, and 25). Examination of these results showed that the normalization factors were a function of the particular photographic emulsion, batch, and age. The betatron calibration planned for the Operation Redwing film emulsions could not be accomplished because of schedule difficulties among NBS, NOL, and this laboratory. Comparison of Co^{60} calibration curves for the various Operation Redwing emulsions with similar curves for Operation Teapot indicated so little change that the Operation Teapot average betatron normalization factor (0.863 ± .031) rounded off to 0.9 was used for all Operation Redwing emulsions.

Air Force Special Weapons Center (AFSWC), in cooperation with Los Alamos Scientific Laboratory (LASL) and Evans Signal Laboratory (ESL), exposed film to the Godiva bare assembly at Los Alamos in order to study the effects of neutrons on photographic emulsions. Results indicated that the film sensitivity for neutrons was relatively low. This experiment also yielded additional data on rate dependence of these emulsions in that there was no significant change in emulsion response due to a gamma rate of exposure of 1 r/sec as compared to 10^7 r/sec for equivalent total exposure.

The neutron sensitivity of film is considered to consist of two components, a response to low-energy (thermal) neutrons, and a response to high-energy neutrons. As far as could be determined from the experiment, the two components were independent and additive. The calibration data for neutron flux was furnished AFSWC by N-2 division at LASL. It was assumed that any

TABLE 2.5 FILM SENSITIVITY TO NEUTRONS

See Section 2.3.1 for source of data.

DuPont Film	Packet Type	Low Energy (Gold) Neutrons	High Energy Neutron Dose
		$(n/cm^2)\ r \times 10^{-9}$	n rep dose/r
606	606 1290	4.7 ± 2.4	37 ± 22
1290	606 1290	3.9 ± 2.2	31 ± 20
606	553	3.4 ± 1.8	28 ± 17
510	553	2.3 ± 1.4	19 ± 12
502	553	3.2 ± 1.7	26 ± 15

perturbation in flux caused by the NBS film holders would be small. Neutron-sensitivity values were compared to the amount of Co^{60} gamma radiation required to produce the same optical density. Table 2.5 summarizes the data obtained.

For all shots except Cherokee, the relative air densities were 0.895 ± .002. For Cherokee it was 0.847; however, the data were adjusted to a relative air density of 0.895 to permit comparison of results. No air-density adjustment was made for the other events.

In analyzing the initial data to determine the flux that existed outside the station, it was important to take into account the attenuation offered by the station and the instrumentation inside. Table 2.6 presents a list of station types and calculated shielding correction factors based on a 3.5-Mev gamma energy in accordance with the assumptions of Reference 25. A mutual instrument-shielding correction factor for each station type was estimated and is given in Table 2.6.

TABLE 2.6 INITIAL-GAMMA-EXPOSURE CORRECTION FACTORS

Station Series	Station Shielding	Mutual Shielding	Combined Quartz Fiber and Chemical Correction Factor	Betatron Film Normalization	Combined Film Correction Factor
210 210' without quartz	1.05	1.05	1.10	0.90	1.0 ± 0.05
211 fiber rate 212 device	1.35	1.10	1.48	0.90	1.35 ± 0.10
210' with quartz 211 fiber rate 212 device	1.40	1.15	1.61	0.90	1.45 ± 0.10
213	1.20	1.05	1.26	0.90	1.15 ± 0.05
113	1.15	1.05	1.21	0.90	1.10 ± 0.05

An experimentally determined film betatron calibration factor of 0.9 is also listed. The combined correction factors were computed from the above-mentioned factors. The betatron calibration factor applied to the film only. No betatron calibration data were available for the quartz fiber and chemical dosimeters, and a factor of 1.0 was assumed.

The combined correction factor was used only in the analysis of the initial-gamma-exposure data in Table 3.16. Uncorrected exposure values are listed in the individual shot tables in Chapter 3.

2.3.2 Residual-Exposure Calibration. In order to evaluate the initial-gamma exposure, it was often necessary to estimate the residual-gamma exposure. Some of the dosimeters associated with the quartz-fiber device and the mechanical dropping mechanism yielded measurements of residual-gamma radiation. Over the limited areas of interest (500 feet or less) the fallout pattern was generally continuous and exposures did not vary greatly, hence it was possible to estimate the exposures at stations where no specific data were available. These estimates were consistent both with calculations based on measurements of residual-gamma intensity made at the time of station instrument recovery and with integrated rate versus time measurements made by Project 2.2. Stations located on the reef and in the tidal wash area were evaluated separately, since the residual exposure in these areas could have been reduced by a factor of ten, depending on the water-land geometry and tidal wash. In cases where the estimated residual exposure exceeded the resultant initial exposure, an additional uncertainty factor had to be added to the normal accuracy factor.

It was desirable to correct the residual-exposure values obtained inside the station to those that would exist outside the station if the dosimeters were unshielded. To determine this correction factor, dosimeters were wired flush to the outside of some stations where they would be expected to survive the blast and thermal effects of the event. In some cases, four instruments uniformly spaced about an 8-inch (outside diameter) pipe were used. The variation of exposure in each instrument set was due primarily to the land-water geometry. Since the station still shielded the instruments from 4π radiation, the results obtained did not directly yield the correction factor. Therefore, attenuation factors were calculated based on station construction assuming 700 kev as the effective energy of the residual-gamma radiation (Table 2.7). These were consistent with experimental results.

TABLE 2.7 RESIDUAL-GAMMA-EXPOSURE CORRECTION FACTORS

Station Series	Station Attenuation	Instrument Attenuation	Combined Quartz Fiber	Film - Quartz Fiber Normalization	Combined Film
210	1.12	1.12	1.25	1.15	1.44
210' without quartz 211 fiber rate 212 device	1.85	1.24	2.30	1.25	2.88
210' with quartz 211 fiber rate 212 device	2.00	1.36	2.72	1.25	3.40
213	1.48	1.12	1.66	1.20	2.00
113	1.36	1.12	1.52	1.20	1.83

Figures 2.7 through 2.11 show the energy response of Dupont Emulsions 502, 510, and 606 in NBS holders, and of quartz-fiber dosimeters and the AN/PDR-39 relative to Co^{60}. Since the response of the quartz-fiber dosimeter was found to be most desirable during previous operations (Reference 4), experimental factors were evaluated to adjust the film readings to quartz-fiber equivalence. These factors were 1.15 for film in aluminum containers and 1.25 for film in 8-inch steel-pipe stations (Table 2.7). The factors in Table 2.7 were considered accurate to within 20 percent because of variations in thickness of blast shielding. Residual-exposure data that

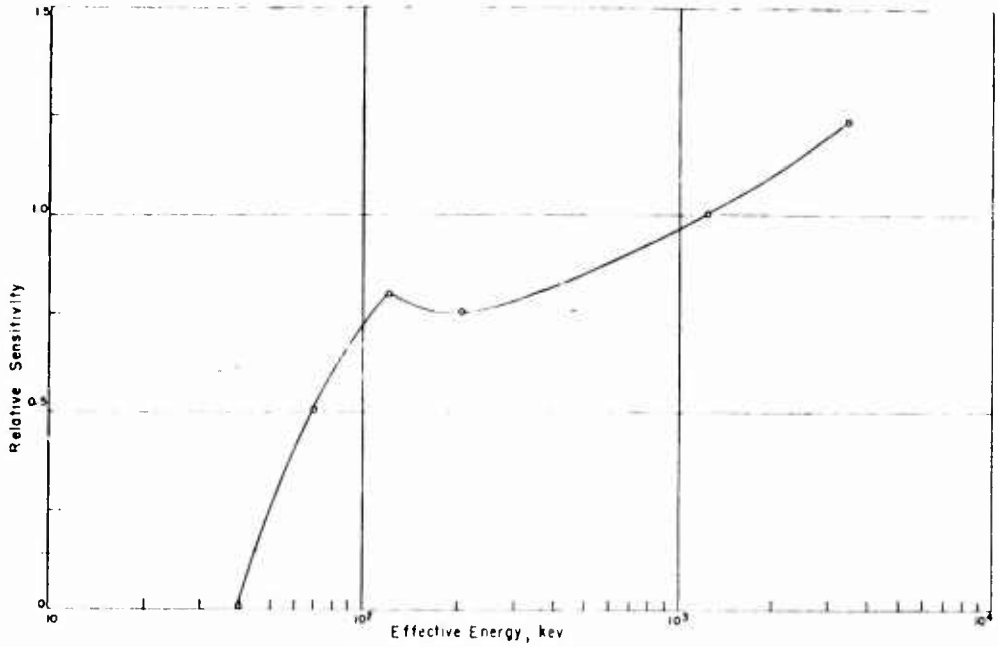

Figure 2.7 DuPont 502 energy dependence curve normalized to Co^{60} value. (Film in NBS holder.)

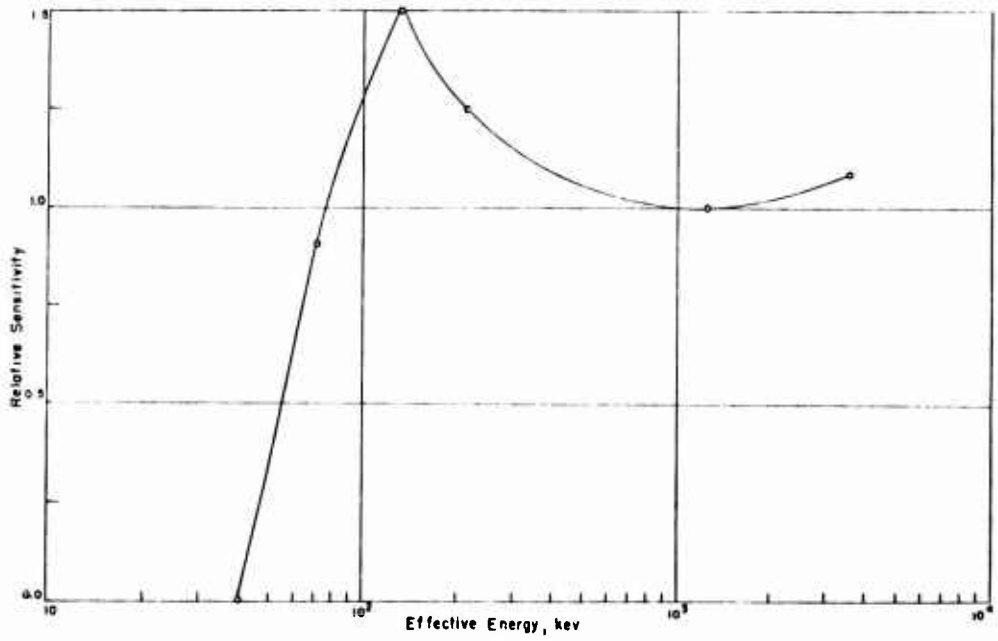

Figure 2.8 DuPont 510 energy dependence curve normalized to Co^{60} value. (Film in NBS holder.)

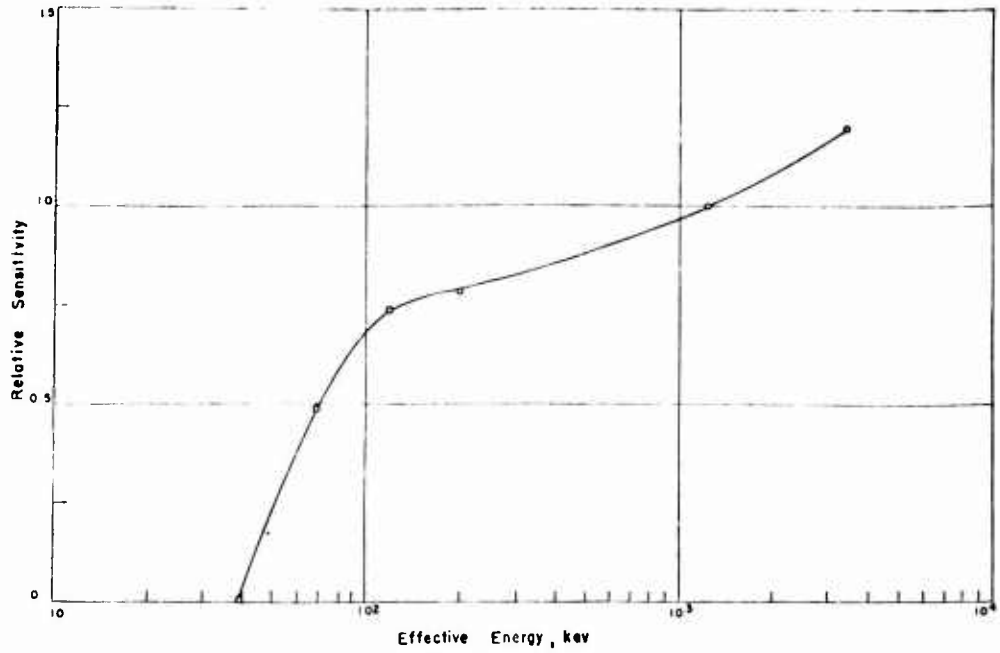

Figure 2.9 DuPont 606 energy dependence curve normalized to Co^{60} value. (Film in NBS holder.)

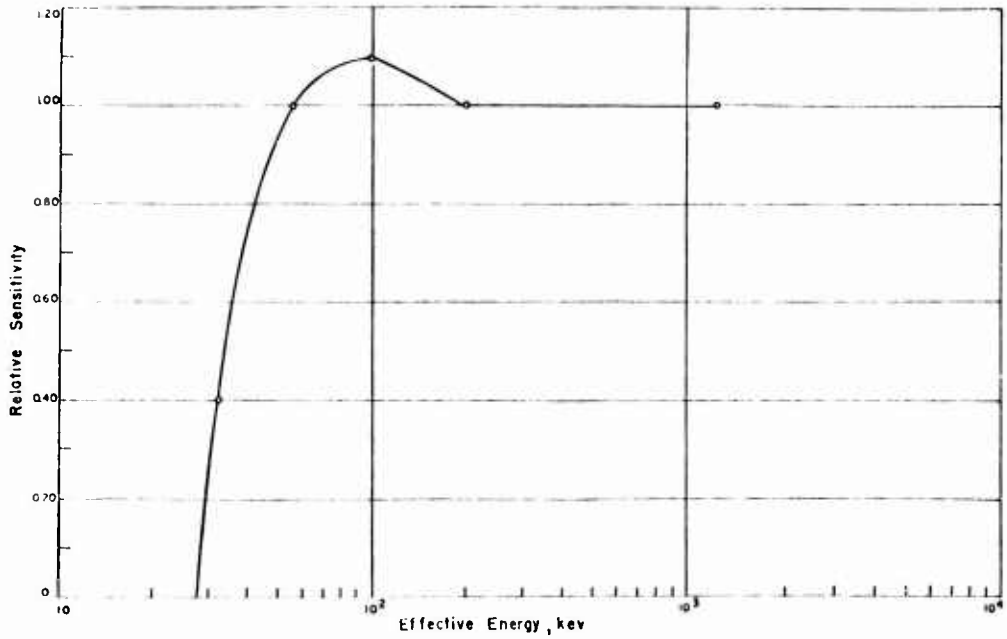

Figure 2.10 Quartz fiber dosimeter energy dependence curve normalized to Co^{60} value.

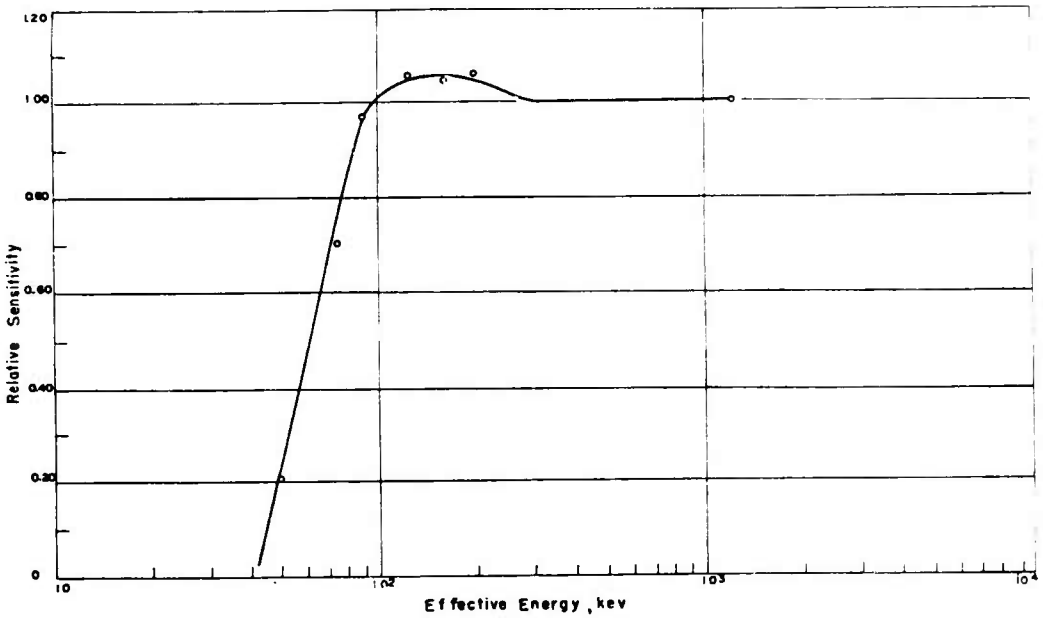

Figure 2.11 AN/PDR-39 energy dependence curve normalized to Co^{60} value.

appear in the individual shot reports were uncorrected. The correction factors were used only in computing information included in Figures 3.5 through 3.8.

2.4 SUPPORT FACILITIES

The following projects were furnished NBS photographic dosimeters in the quantities listed: Project 2.2, 100; Project 2.63, 300; Project 2.65, 150; Project 2.66, 150; and Project 2.72, 30. Small quantities were also used by Projects 2.51, 4.1, and TU 7. These dosimeters were processed and the results returned to the interested projects. Instruments were exposed to the 200-curie, 4π Co^{60} source, and an 80-curie, collimated Co^{60} source for Projects 2.63, 2.65, 2.66, 2.8, and 4.1.

Chapter 3
RESULTS and DISCUSSION

This chapter presents raw data based on Co^{60} calibration and discussion necessary to clarify the tables. The terms thermal, blast, 1-minute, total, and rate device refer to timing (Sections 2.2.6 and 2.2.7), and down refers to dosimeters that were placed in the bottom of the pipe stations. The terms front, left, rear, and right refer to instruments wired flush to the outside of the stations, with respect to an observer at ground zero facing the station. Instrumentation and recovery rates refer to residual gamma field intensities at the times of instrumentation and recovery of instruments located at an exposure station.

3.1 SHOT LACROSSE

One piece of initial-gamma exposure data was obtained on this event at a Project 2.65 station on Site Yvonne. Initial (total exposure) was 5.3 r, distance 8,088 feet, yield 38.5 ± 3 kt, and relative air density 0.893. Instrumentation and recovery rates were negligible.

3.2 SHOT CHEROKEE

All stations other than those listed in Table 3.1 received less than [ ] Film at the Series 250 and 251 stations was damaged by water or sulphur fumes from damaged neutron-threshold detectors. Therefore, the results were not included.

The exposures at the stations listed in Table 3.1 were possibly from initial-gamma radiation. Temperature effects on the film could have caused an increase in background density, as discussed in Section 2.2.1. However, careful re-examination of all data did not reveal any such temperature or aging effects present in the Shot Cherokee data. The presence of low-energy gamma components in the residual field was indicated by the higher exposures measured by films exposed without NBS holders. The instrumentation and recovery rates were negligible.

3.3 SHOT ZUNI

Table 3.2 lists the total exposure on Shot Zuni. Table 3.3 lists the initial gamma exposure for the same shot. Eight-inch steel-pipe stations were installed at Stations 210.23′, 210.27′, 210.30′, and 210.34′. The rate device at 210.27′ became wedged in the station and failed to drop. The cap of Station 210.30 was broken by the shock and the instruments fell immediately. [ ] Another rate device at Station 210.34′ without a dropping mechanism yielded only total exposure information.

A mechanical drop mechanism installed in a water-filled steel pipe at Station 210.23′ functioned properly because the dosimeters were dropped in correct sequence. The water was used for additional shielding, since the depth of the instrument mount was only 2 feet below the surface. The initial-gamma exposures for this event were lower than anticipated; moreover, the gamma exposure was lower than expected for the measured yield. All the film that dropped read less than 1 r.

3.4 SHOT FLATHEAD

Tables 3.4 and 3.5 list instrumentation and recovery and initial exposure, respectively, for Shot Flathead. The disparity between the film and quartz-fiber exposures at Station 212.03 was

TABLE 3.1 SHOT CHEROKEE DATA

Station Number	Location	Slant Distance	Exposure in NBS Holder	Exposure no NBS Holder
		ft	r	r
112.01	Charlie	19,080	—	0.39
113.01	C-D Reef*	18,360	0.45	0.42
113.02	C-D Reef*	17,860	0.47	0.59
113.03	C-D Reef*	17,100	0.80	0.96
113.04	C-D Reef*	17,300	0.51	0.70
113.05	C-D Reef*	17,970	0.22	0.28
113.06	C-D Reef*	19,120	0.12	0.13

* Charlie-Dog

TABLE 3.2 SHOT ZUNI TOTAL-EXPOSURE

Shot time was 0556, 28 May 1956.

Station	Location	Date	Recovery Time	Rate	Total Gamma Exposure		
					Film	Quartz Fiber	Chemical
				mr/hr	r	r	r
212.01	Able	31 May	0925	1,000	202	221	237
212.02	Charlie	31 May	0920	800	155	135	200
212.03	Dog	31 May	0915	1,200	185	195	262
212.04	Easy	31 May	0910	1,200	152	185	—
212.05	Fox	31 May	0905	1,200	207	222	—
212.06	George	31 May	0900	1,200	118	124	92
How	How	31 May	0845	330	44	60	—
Nan	Compound	28 May	1400	0	0.31	—	—
Nan	Airstrip	28 May	1430	0	0.31	—	—
210.22	Oboe Reef	31 May	1030	50	17.5	—	—
210.23	Oboe	29 May	1330	600	93	—	—
210.23'	Oboe	29 May	1330	600	37	—	—
210.24	Oboe Reef	31 May	1030	50	11	—	<50
210.25	Oboe Reef	†	†	†	†	†	†
210.26*	Peter Reef	31 May	1030	50	25	—	<50
210.26*	Peter Reef	31 May	1030	50	69	—	75
210.27*	Peter	29 May	1315	1,200	200	—	220
210.27'*	Peter	29 May	1315	1,200	102	136	125
210.29	Roger	7 June	—	—	2,500	—	—
210.30*	Roger	29 May	1300	1,300	16,000	—	-
210.31	Roger	†	†	†	†	†	†
210.32	Uncle	†	†	†	†	†	†
210.33*	Uncle Reef	30 May	1300	50	1,800	—	850
210.34*	Uncle	29 May	1230	1,000	465	—	420
210.34'*	Uncle	29 May	1230	1,000	335	368	—
210.35*	Uncle Reef	31 May	1005	20	205	—	—
210.37	William	31 May	1000	420	143	200	225
210.38	Yoke	31 May	0950	300	100	120	125
210.39	Zebra	31 May	0945	260	92	108	118
210.40	Alfa	31 May	0940	320	110	118	75
210.41	Bravo	31 May	0935	220	85	100	75

* These stations received both initial and residual radiation as shown in Table 3.3. All other exposures are residual only.

† Destroyed.

TABLE 3.3 SHOT ZUNI INITIAL-GAMMA EXPOSURE

All of the data in this table are from film at aluminum stations except those referred to in * and †.

Station Number	Location	Distance	Total Exposure	Estimated Residual Exposure	Resultant Initial Exposure
		ft	r	r	r
210.30	Roger	7,000	16,000	150	15,850
210.29	Uncle Reef	8,500	2,500	15	2,485
210.33	Uncle Reef	9,420	1,880	15	1,785
210.33	Uncle Reef	9,420	850*	15	835
210.34	Uncle	10,320	465	150	315
210.35	Uncle Reef	10,935	205	15	190
210.27	Peter	11,270	200	150	50
210.27'	Peter	11,270	145†	100	45
210.56	Peter Reef	11,510	69	15	54
210.26	Peter Reef	12,940	25	15	10

* These data are from a chemical dosimeter.

† These data are from a quartz fiber exposure versus time device in a steel station.

TABLE 3.4 SHOT FLATHEAD FOX-COMPLEX INSTRUMENTATION AND RECOVERY

Shot time was 0626, 12 June 1956.

Station Number	Location	Instrumentation		Recovery	
		Date	Time	Date	Time
213.01	MM3	8 June	1350	16 June	1430
212.03	Dog	6 June	1045	14 June	1545
213.02	Dog	8 June	1400	14 June	1530
211.01	Dog	6 June	1115	14 June	1524
213.03	Easy	8 June	1445	14 June	1518
211.02	Easy	6 June	1210	14 June	1515
212.04	Easy	9 June	1200	14 June	1512
211.03	Fox	6 June	1320	14 June	1505
212.05	Fox	6 June	1345	14 June	1405
213.04	Fox	No Record	—	14 June	1400
211.04	George	No Record	—	No Record	—
211.06	George	No Record	—	No Record	—

not fully understood. At Station 212.05 the 10-r thermal and blast exposures were the result of residual contamination from Shot Zuni. Film indicated about [redacted] initial exposure, and quartz-fiber dosimeters indicated about [redacted] The switches in the mechanical drop devices at Stations 213.02, 213.03, and 213.04 functioned, but the dosimeters did not fall below the surface because of a constriction in the pipes.

Table 3.6 and Figure 3.1 give results from the quartz-fiber rate devices for exposure versus time.

The rate device at Station 211.01 did not drop; therefore it was necessary to subtract the residual exposure of [redacted]. At Station 210.02, it was assumed that the [redacted] that arrived after 15 seconds was residual since the shielding was only 90 percent effective. The device at Station

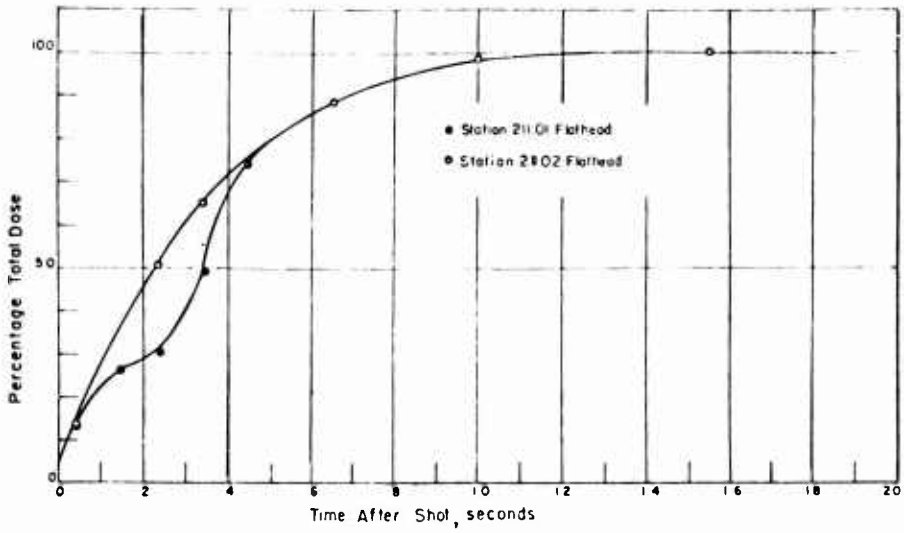

Figure 3.1 Initial-gamma exposure versus time for quartz fiber rate device.

212.04 operated in reverse, yielding only total residual information. The exposure at Station 211.03 was small and could not be resolved properly.

Table 3.7 lists installation, recovery, and residual exposure information. Project 2.2 information indicated that Stations 210.23 to 210.41 received about [redacted] of fallout exposure from this shot, the remainder having come from Shot Zuni.

3.5 SHOT DAKOTA

Tables 3.8 and 3.9 list instrumentation and recovery and initial exposure, respectively, for Shot Dakota. High residual-gamma exposure rates resulted from Shot Flathead at the time of the Shot Dakota instrumentation. Therefore, it was necessary to keep the instrumentation to a minimum. The project was not aware of the change in shot coordinates at the time of instrumentation, and since the shot was moved about ½ mile closer to the Fox complex, the lowest initial exposure recorded was about [redacted]

Dosimeters were placed in two locations on Man-Made Island No. 3 prior to Shot Flathead. One group of dosimeters was found during Flathead recovery, and the second group was recovered after Shot Dakota. A Shot Dakota data point was obtained by subtracting the Shot Flathead exposure.

3.6 SHOT NAVAJO

Tables 3.10, 3.11, and 3.12 list instrumentation and recovery, initial-gamma exposure, and residual exposure, respectively, for Shot Navajo. Some phenomenon, perhaps the shock, caused

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TABLE 3.8 SHOT DAKOTA INSTRUMENTATION AND RECOVERY

Shot time was 0606, 26 June 1956.

Station Number	Instrumentation Location	Instrumentation Date	Instrumentation Time	Recovery Date	Recovery Time
212.03	Dog	16 June	1510	5 July	0925
211.01	Dog	16 June	1515	5 July	0930
211.02	Dog-Easy	16 June	1520	5 July	0935
212.04	Easy	16 June	1525	5 July	0940
213.01	Man-Made 3	8 June	1400	5 July	0920

all the quartz-fiber dosimeters in the rate devices to activate at an early time. As a result, they yielded only total initial plus residual exposure data. Station 211.01 was partially blown out of the ground. The rate device did not drop, thus the station yielded only total initial plus residual exposure information. The 1-minute drop timers were corroded and did not function. Consequently, the estimates of residual exposure on Sites Dog and Easy were not accurate.

3.7 SHOT TEWA

Table 3.13 gives Shot Tewa instrumentation and recovery data, and Table 3.14 shows residual-exposure data. Data from the Charlie-Dog reef, including scattered initial-gamma data is listed in Table 3.15.

Total-gamma exposures at Stations 113.03 and 113.09 were well established. Residual-exposure estimates were obtained from Stations 113.02 and 113.03. These stations were in the same general

TABLE 3.9 SHOT DAKOTA INITIAL EXPOSURE

Shot time was 0606, 26 June 1956.

Station Number	Timing	Film Exposure	Calculated Preshot Residual	Estimated Postshot Residual	Initial	Distance
		r	r	r		ft
212.03	Total Blast	1.17×10^5 1.67×10^4	105	50	1.17×10^5	4,422
211.01	Total Blast	2.48×10^4 4,600	90	50	2.47×10^4	5,500
213.01	Total	5,175 †	15	25	5,135	6,605
211.02	Total Blast	4,600 1,060	65	50	4,485	6,650
212.04	Total 1 minute	880 830	65	50 *	705	7,220

* This result was obtained by subtracting the 1-minute value from the total value. The other estimates were based on this value.

† This result was obtained by subtracting the total Flathead exposure value of 725 r from the Flathead plus Dakota exposure value of 5,900 r.

area and had the same geometry and recovery rates but were in a region where the initial-gamma exposures were negligible. Film at Stations 113.04, 113.07, and 113.08 read greater than 70,000 r. The chemical data at 113.04 appeared valid. The chemical data at Station 113.08 was probably in error, since it contradicted both the film data at Station 113.08 and the chemical data at Station 113.04, and was far below the predicted level. The exposures expected at Station 113.07 were far above the useful range of the chemical dosimeters and it is probable that they saturated, and that the actual exposure was much greater than 650,000 r. There was no satisfactory explanation for the discrepancies that occurred in the chemical data derived from Stations 113.07 and 113.08. The discrepancies observed in the chemical data from 113.07 and 113.08 suggested that the reliability of the chemical dosimeter systems might have been questionable when they were used in the environment which existed at Stations 113.04, 113.07, and 113.08. These chemical dosimeters were exposed to a total gamma dose that was much higher than their upper range, and they were probably exposed at a very high dose rate and to a very high neutron flux.

It was felt that the initial-exposure data from 113.03 was reliable since the total exposure was well established and the residual estimate was valid. Data from Stations 113.03, 113.04, and 113.09 agreed with results from previous events.

TABLE 3.10 SHOT NAVAJO INSTRUMENTATION AND RECOVERY

Shot time was 0556, 11 July 1956.

Station Number	Location	Instrumentation Date	Instrumentation Time	Recovery Date	Recovery Time
210.19	Fox	7 July	1530	13 July	1108
210.20	George	7 July	1540	13 July	1050
210.23	Oboe	5 July	0750	13 July	1132
210.27	Peter	5 July	0755	13 July	1125
210.30	Roger	5 July	0800	13 July	1120
210.34	Uncle	5 July	0808	13 July	1110
210.37	William	5 July	0815	13 July	1100
210 38	Yoke	5 July	0822	13 July	1025
210.39	Zebra	5 July	0827	13 July	1015
210.40	Alfa	5 July	0832	13 July	1010
210.41	Bravo	5 July	0835	13 July	0958
212.01	Able	5 July	0848	13 July	0945
212.02	Charlie	5 July	0857	13 July	0930
113.07	M M No. 1	5 July	0905	13 July	0922
113.08	M M No. 2	5 July	0910	13 July	0920
113.09	M M No. 3	5 July	0920	13 July	Destroyed
212.03	Dog	7 July	1420	13 July	1425
212.04	Easy	7 July	1230	13 July	1315
212.05	Fox	7 July	1125	13 July	1117
212.06	George	7 July	1000	13 July	1000
211.01	Dog	7 July	1400	13 July	1405
211.02	Dog-Easy	7 July	1335	13 July	1355
211.03	Easy-Fox	7 July	1340	13 July	1240
211.04	Fox-George	7 July	1020	13 July	1055
213.02	Dog	7 July	1410	13 July	1415
213.04	Fox	7 July	1040	13 July	1110

TABLE 3.13 SHOT TEWA INSTRUMENTATION AND RECOVERY

Shot time, 0546, 21 July 1956.

Station	Location	Position	Instrumentation			Recovery		
			Date	Time	Rate	Date	Time	Rate
					mr/hr			mr/hr
212.01	Able	Front	15 July	1010	90	24 July	1420	4,000
		Right	—	—	90	—	—	—
		Rear	—	—	90	—	—	—
		Left	—	—	90	—	—	—
212.02	Charlie	Front	15 July	1000	32	24 July	1425	3,000
		Right	—	—	47	—	—	—
		Rear	—	—	38	—	—	—
		Left	—	—	27	—	—	—
113.01	Charlie-Dog Reef	—	16 July	1645	4	25 July	1750	8
113.02	Charlie-Dog Reef	—	16 July	1625	3	25 July	1755	20
113.03	Charlie-Dog Reef	—	16 July	1600	3	25 July	1810	40
113.04	Charlie-Dog Reef	—	16 July	1510	4	25 July	1825	18
113.05	Charlie-Dog Reef	—	16 July	1440	0 to 2	25 July	Destroyed	
113.07	M M No. 1	—	16 July	1400	90	25 July	1100	1,000
113.08	M M No. 2	—	16 July	1250	120	24 July	1430	2,800
113.09	M M No. 3	—	16 July	1200	80	25 July	1115	3,500
212.03	Dog	Front	15 July	0945	80	25 July	0930	1,500
		Right	—	—	100	—	—	—
		Rear	—	—	100	—	—	—
		Left	—	—	70	—	—	—
212.04	Easy	Front	15 July	0950	60	24 July	1050	2,400
		Right	—	—	80	—	—	—
		Rear	—	—	100	—	—	—
		Left	—	—	60	—	—	—
212.05	Fox	Front	15 July	0935	60	24 July	1110	3,000
		Right	—	—	65	—	—	—
		Rear	—	—	70	—	—	—
		Left	—	—	60	—	—	—
212.06	George	Front	15 July	0925	30	24 July	1120	1,000
		Right	—	—	45	—	—	—
		Rear	—	—	70	—	—	—
		Left	—	—	45	—	—	—
210.23	Oboe	—	15 July	1105	8	24 July	1320	6
210.27	Peter	—	15 July	1100	4	24 July	1330	8
210.30	Roger	—	15 July	1056	9	24 July	1335	18
210.34	Uncle	—	15 July	1047	4	24 July	1342	220
210.37	William	—	15 July	1038	8	24 July	1350	1,000
210.38	Yoke	—	15 July	1033	5	24 July	1355	1,000
210.39	Zebra	—	15 July	1030	9	24 July	1400	1,500
210.40	Alfa	—	15 July	1025	8	24 July	1402	2,200
210.41	Bravo	—	15 July	1020	7	24 July	1404	2,200

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TABLE 3.14 SHOT TEWA RESIDUAL EXPOSURE

Station Number	Exposure			
	Quartz Fiber	Position	Film	Position
	r		r	
210.23	3.8	—	2.51	—
	2.0	rear	—	—
210.27	6.5	—	3.67	—
210.30	8.2	—	6.45	—
210.34	98	—	82.6	—
	160	rear	93.5	rear
210.37	510	—	391	—
210.38	525	—	454	—
210.39	800	—	627	—
210.40	1,300	—	1,045	—
210.41	825	—	755	—
212.01	2,300	—	2,833	front
	—	—	1,916	right
	—	—	3,016	rear
	—	—	2,400	left
212.02	890	—	823	—
	2,650	rear	1,000	front
	—	—	1,485	right
	—	—	1,460	rear
	—	—	940	left
212.03	695	—	610	—
	1,102	rear	580	front
	—	—	920	right
	—	—	860	rear
	—	—	762	left
212.04	510	—	375	—
212.05	521	—	399	—
	1,027	rear	700	front
	—	—	710	right
	—	—	668	rear
	—	—	640	left
212.06	240	—	201	—

TABLE 3.15 SHOT TEWA INITIAL-GAMMA EXPOSURE

Station	Distance	Total Dose		Estimated Residual	Initial
		Film	Chemicals		
	ft	r	r	r	r
113.01	15,850	160	250	160 to 250	—
113.02	14,380	250	250	250	—
113.02	14,380 *	400	—	400	—
113.02	14,380 *	580	—	580	—
113.02	14,380 *	820	—	820	—
113.03	10,500	3,300	2,500	250	2,650
113.04	6,760	$>7 \times 10^4$	3.35×10^5	250	3.35×10^5
113.05		Destroyed			
113.06		Destroyed - Not Instrumented			
113.07	2,875	$>7 \times 10^4$	6.5×10^5†	800	Very great
113.08	5,940	$>7 \times 10^4$	42,000‡	800	$>7 \times 10^4$
113.09	10,830	1,950	—	800	1,150

* These films were located on the outside of the steel-pipe stations. All other dosimeters were located inside the stations.

† Exposures anticipated at this station were far above the intended range of this dosimeter, and the instrument probably saturated.

‡ As indicated in the text, this is probably in error. No explanation can be offered as to why this reading is lower than that of 113.04.

3.8 DISCUSSION

Table 3.16 summarizes Operation Redwing initial-gamma exposure data, and Table 3.17 gives the total yield, fission yield, and relative air density for each event. Figures 3.2, 3.3, and 3.4 are plots of the Redwing initial-gamma exposure versus distance and the TM 23-200 curves for similar total yield. This method of computation neglects the effect of relative fission and fusion contributions to the total yield. Correction factors discussed in Section 2.3.1 have been applied to adjust the raw data to unshielded, betatron-calibrated exposure values. Shot Cherokee data were adjusted to relative air density of 0.895. The initial-gamma exposure from Shots Cherokee, Zuni, and Navajo at 3 miles was about 1 r. The accuracy of the initial-gamma exposure data as corrected was within ± 30 percent.

Figures 3.5 through 3.8 show the total residual-gamma exposures plotted on maps. These exposures were corrected for station shielding and spectral response of the dosimeters (Section 2.3.2). In addition, all the values from a given shot were adjusted to the same recovery time using recovery rates, and assuming a decay exponent of -1.2. Individual stations, such as the one on Site Charlie, may have shown reduced amounts of exposure because they were near the lagoon. The accuracy of the residual-gamma data presented in this section was within ± 50 percent.

TABLE 3.16 REDWING INITIAL-GAMMA EXPOSURE

Shot	Station	Uncorrected Initial	Combined Correction Factor	Corrected Initial	Distance
Zuni	210.30	15,850	1.0	15,850	7,000
	210.29	2,485	1.0	2,485	8,500
	210.33	835	1.0	835	9,420
	210.34	315	1.0	315	10,320
	210.35	190	1.0	190	10,935
	210.56	54	1.0	54	11,510
	210.26	10	1.0	10	12,940
Tewa	113.04	3.35×10^5	1.21	4.05×10^5	6,760
	113.03	2,650	1.1	2,915	10,500
	113.09	1,150	1.1	1,265	10,830

* Cherokee exposure adjusted to 0.895 relative air density.
† Station contained a rate device.

TABLE 3.17 YIELDS AND RELATIVE AIR DENSITIES

Shot	Total Yield, Mt	Relative Air Density
Cherokee		0.847
Zuni	3.53	0.894
Flathead		0.896
Dakota		0.893
Navajo		0.895
Tewa	5.01	0.893

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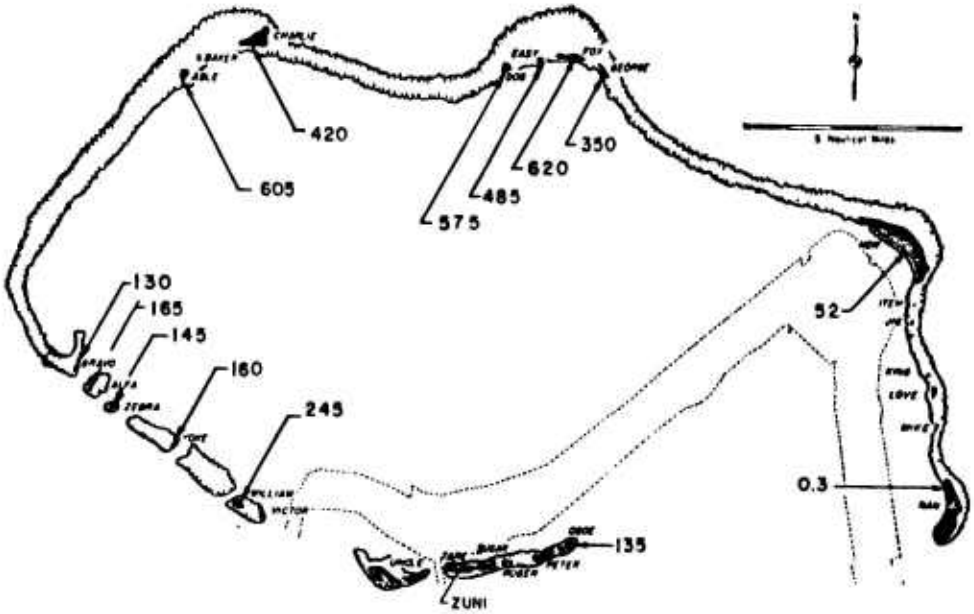

Figure 3.5 Shot Zuni 76-hour residual exposure (roentgens).

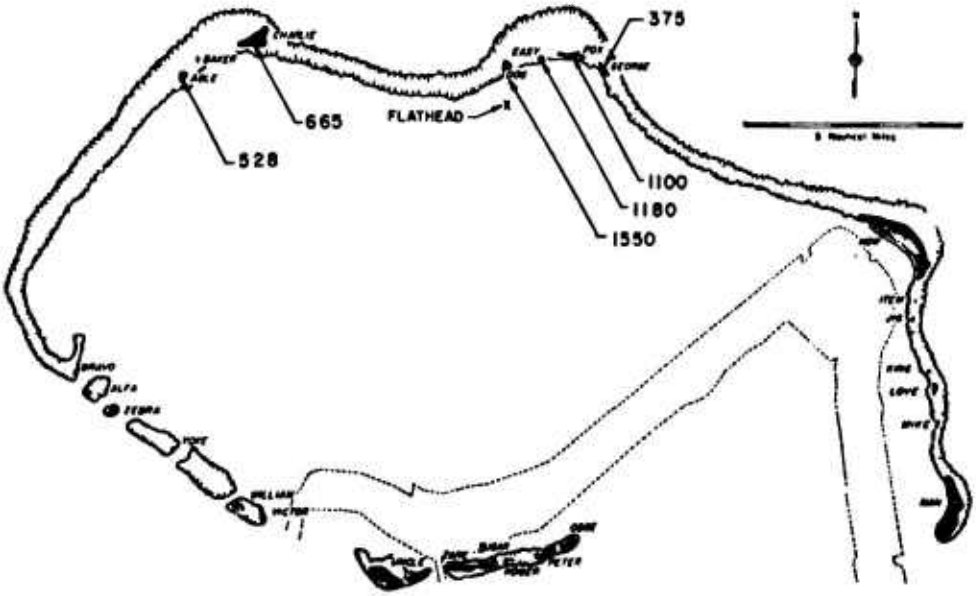

Figure 3.6 Shot Flathead 72-hour residual exposure (roentgens).

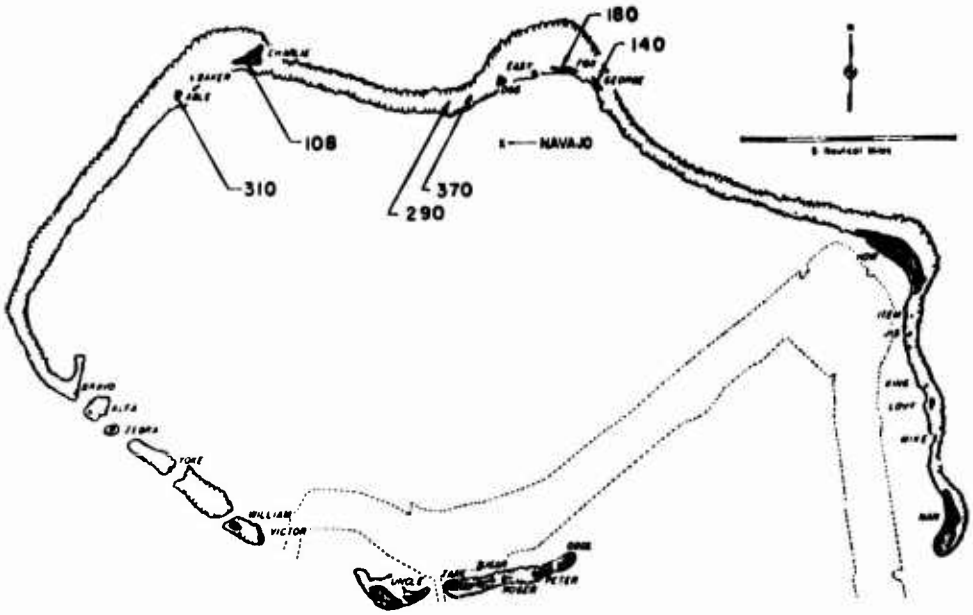

Figure 3.7 Shot Navajo 48-hour residual exposure (roentgens).

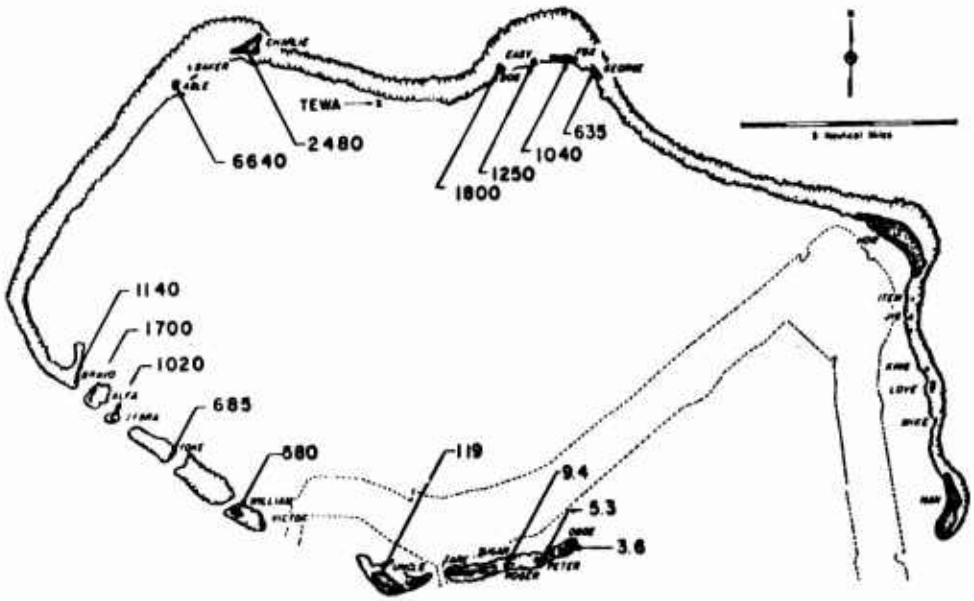

Figure 3.8 Shot Tewa 78-hour residual exposure (roentgens).

The data from this project are presented to indicate the approximate magnitude of the residual-gamma radiation to be expected from different types of nuclear devices. It is felt that with the exception of Shot Cherokee (for which insufficient data were obtained to form definite conclusions) the objectives of the project were met.

In the case of Shot Cherokee, the burst point was approximately 4 to 5 miles in the downwind direction away from the planned ground zero; this resulted in no downwind stations to document residual radiation from fallout. The ground zero for Shot Tewa was moved from its planned location off Site Dog to a location approximately between Sites Charlie and Dog. It was therefore necessary to improvise stations at available locations on the man-made islands and the reef be-

tween Sites Charlie and Dog. Data points were obtained at distances of about 3,000, 7,000, and 10,000 feet, where the initial could be separated from the residual radiation.

In order to compare this project's initial-gamma data with data from previous high-yield shots, reference is made to the Nuclear Radiation Handbook (AFSWP-1100, Figure 3.2.6, page 65), which gives experimental values of DR^2/W for various high-yield shots of Operations Greenhouse, Ivy, and Castle as compared to average values for a large number of low- and intermediate-yield (0 to 100 kt) shots. With the data of this figure as background, additional data from Redwing Shots Flathead, Zuni, Navajo, and Dakota, and Castle Shot Nectar are shown (Figure 3.9). The curves shown for Shots Flathead, Zuni, Navajo, Dakota, and Nectar are the lines of the least-square fit to the DR^2/W-versus-R data normalized (at 2,000 yards) for a relative air density of $\bar{\rho} = 1.0$. This normalization was accomplished by adjusting the slope of the data line (while maintaining the zero-intercept constant) in a manner similar to that used in WT-1115 (Reference 3). Examination of the curves shown in Figure 3.9 indicates that project data agrees with data from all previous operations.

The initial-gamma instrument station locations were selected with an expectation of 50 percent loss per shot; however, the losses were only about 25 percent. The residual instrumentation was nearly 100 percent effective. The secondary and improvised instrumentation for separation of initial- from residual-gamma radiation were only about 40 percent effective throughout the operation.

Chapter 4
CONCLUSIONS

Examination of data indicates the following conclusions:

1. For surface bursts with yields from [redacted] to 5 Mt, and for a [redacted] airburst, initial-gamma radiation is of little military significance to unprotected personnel as compared with thermal and blast damage.

2. The amount of residual-radiation exposure is a function of the fission yield.

3. The curves of initial-gamma exposure versus distance obtained from Project 2.1 data vary from corresponding TM 23-200 curves. The field data falls below predictions at longer ranges and is greater than predicted at shorter ranges. This difference between predicted and field data increases with increasing yield.

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