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OPERATION REDWING

PROJECT 2.1

GAMMA EXPOSURE VERSUS DISTANCE (U)

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Operation Redwing Final Report Project 2.1

GAMMA EXPOSURE VERSUS DISTANCE

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July 1957

U. S. ARMY SIGNAL ENGINEERING LABORATORIES
FORT MONMOUTH, N. J.

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ABSTRACT

The objectives of Project 2.1 were: 1) to determine gamma exposures versus distance from the point of detonation of various high-yield thermonuclear devices; and 2) to draw conclusions from the data concerning gamma exposure contours for various types of detonations, and the validity of scaling laws.

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 and for station shielding. All detectors were calibrated with Co^{60} sources. Photographic dosimeter film-badge service and Co^{60} calibration facilities were provided to other projects as requested.

Initial gamma radiation was measured by 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 Chero-kee, Zuni, and Navajo was about 1 r. Consequently, initial gamma radiation is 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 fall below predictions at longer ranges, and cross over to be greater than predicted at shorter ranges. This difference between predicted and field data increases with increasing yield.

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For residual gamma radiation measurements, instrument stations were located on almost every island of Bikini Atoll. 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.

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FOREWORD

This report presents the results of one of the 48 projects that participated in the Military Effects Program of Operation Redwing. The operation included 17 test detonations. Readers who are interested in other pertinent test information may refer to ITR-1344, Summary Report of the Commander, Task Unit Three. This summary report contains the following general information:

a. An overall description of each detonation, including yield, height of burst, ground zero location, time of detonation, and ambient atmospheric conditions at detonation for the 17 shots.

b. A discussion of all project results.

c. A summary of each project, containing objectives and results.

d. A complete listing of all reports that cover the Military Effects Test Program.

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PREFACE

Acknowledgment 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. 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, Corshie, and Buterhoff, for making available the ABC dosimeter systems described herein; Doctors Taplin and Sassen, University of California, for their production and evaluation of the ABC 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 Charlie-Dog Reef for Shots Cherokee and Tewa; and Majors Roy Weidler and Thomas Connolly, of Headquarters, AFSWP, for technical suggestions and advice.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES

The objectives of Project 2.1 were: 1) to determine gamma exposures versus distance from the point of detonation of various high-yield thermonuclear devices; and 2) to draw conclusions from the data concerning gamma exposure contours for various types of detonations, and the validity of scaling laws. A secondary objective was to determine the gamma exposures received in several discrete time intervals between time of arrival of the thermal pulse and one 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 (References 2, 3, and 4). 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 (Reference 5). This was

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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 an inhomogeneity of the air 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 (Reference 2). Some high-yield 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 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 the 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 NBS, made residual gamma exposure measurements of a 1-kt surface blast and a 1-kt weapon detonated at a depth of 17 feet (Reference 7). During Teapot the U. S. Army Signal Engin Laboratories made measurements of residual-gamma exposure resulting from

[redacted]

an underground blast of a low-yield device (Reference 3).

The advent of high-yield thermonuclear weapons 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 weapons 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 contribution to initial gamma radiation is from the fission-product gammas and the radiation from neutron capture by N^{14} (n,γ) in the HE components and air. The prompt gammas are nearly all absorbed in the device itself and are of little significance outside of the device. The fission-product gammas predominate at close distances (Reference 8). The N^{14} (n,γ) gammas become increasingly important at greater distances,

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TABLE 1.1 ENERGY PARTITION IN FISSION
(Reference 8)

MECHANISM	PERCENT OF TOTAL FISSION ENERGY	TOTAL ENERGY PER FISSION
	Percent	Mev
Kinetic Energy of Fission Fragments	81	162
Prompt Neutrons	4	8
Prompt Gammas[a]	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

[a]Mostly absorbed in the device

[redacted]

[redacted]

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) for a 1-kt surface burst. With respect to time, the N^{14} (n,γ) radiation is essentially emitted within 0.2 second; the fission-product gammas, however, continue to contribute for the first 30 seconds.

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 due to 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 ten times as great for fusion as for fission, and therefore a large number of gamma photons are contributed by the N^{14} (n,γ) 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.

1.3.2 Residual Gamma Radiation. The residual gamma radiation consists of fission-product radiation from fallout and radiation from neutron-induced activity. The decay rate of the residual radiation from fallout will follow approximately the expressions:

$$I_t = I_1 t^{-1.2} \qquad (1.1)$$

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

where:

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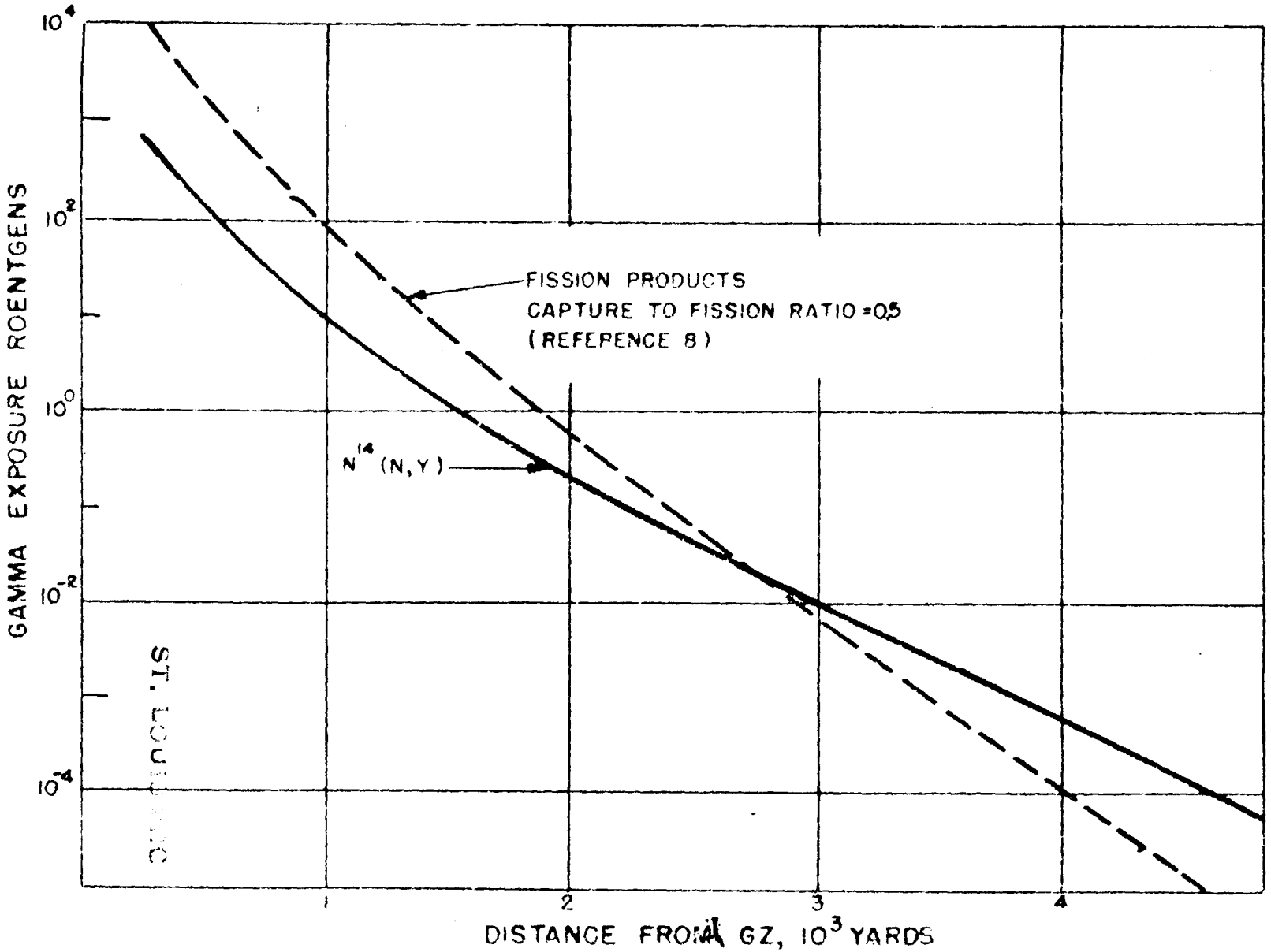

Figure 1.1 Gamma exposure for 1 KT surface burst.

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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 weapon design. For example, the presence of Np^{239} would tend to decrease the absolute value of the decay exponent for a period of time.

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

$$I_D = \frac{I_o e^{-\mu D}}{4\pi D^2} \qquad (1.2)$$

where:

I_D = intensity at distance D

I_o = 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 10), and some values are

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shown in Table 1.2. For omnidirectional detectors, the expression is:

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

TABLE 1.2 CALCULATED BUILDUP FACTORS

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

ENERGY (E_0) Mev	B		
	1000 yds	1500 yds	3000 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

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 weapons of less than 100-kt yield, essentially all of 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 11). 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,

$$M = V_0 \rho_0 = \frac{4\pi R^3 \rho_0}{3} \qquad (1.4)$$

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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

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

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

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

Equation 1.6 indicates that a ray originating in the center of the sphere would traverse only 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 F^{14} (n,γ) component of initial radiation is essentially emitted within 0.2 second. Since it takes at least one second for the shock front to reach a detector at a distance of 7000 feet (even for devices in the order of 6 Mt), the F^{14} (n,γ) 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.

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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 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 EG&G-type film holder. This consists of a bakelite container with a 3.25-mm wall thickness covered with a 1.07-mm layer of tin and a 0.3-mm layer of lead. The lead and tin act as filters to suppress the lower energies sufficiently to keep the response linear above 115 kev. Below 115 kev, the gamma radiation is attenuated excessively, and the exposure due to gammas below 115 kev is 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

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is similar to the initial radiation of the device (Reference 13). The electron equilibrium layer presents a source of electrons that may be 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 is 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 show maximum sensitivity to gamma energies at about 60 kev.

Two dental-size film packets, each containing from one to three different film emulsions, can 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: Dupont 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 2.5 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

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TABLE 2.1 EXPOSURE RANGES OF THE EMULSIONS

Emulsion Type		Range		
		r		
Du Pont	502	0.05	-	10
	510	1.0	-	100
	606	10.0	-	3,000
Eastman	SO 1112	50.0	-	2,500
	548-0 dc	3,000	-	100,000
	548-0 sc	5,000	-	100,000

TABLE 2.2 QUARTZ-FIBER-DOSIMETER RANGES

Bendix No.	Range
	r
622	0 - 20
610 (IM-20/PD)	0 - 50
686 (IM-93/UD)	0 - 600
803	0 - 2000
(IM-107)	0 - 200

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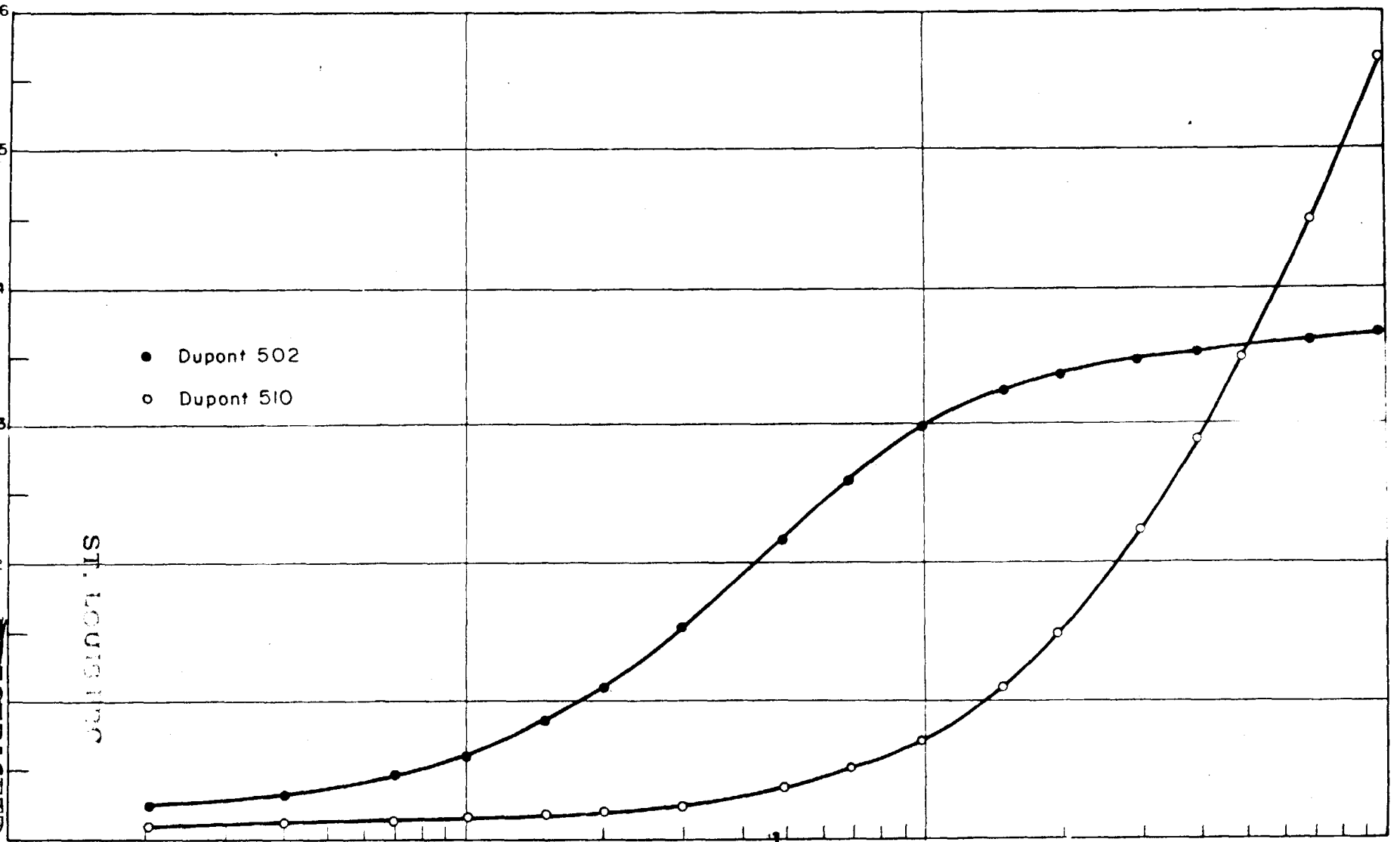

Figure 2.1 Co^{60} calibration for film types. Film in [illegible] holder.

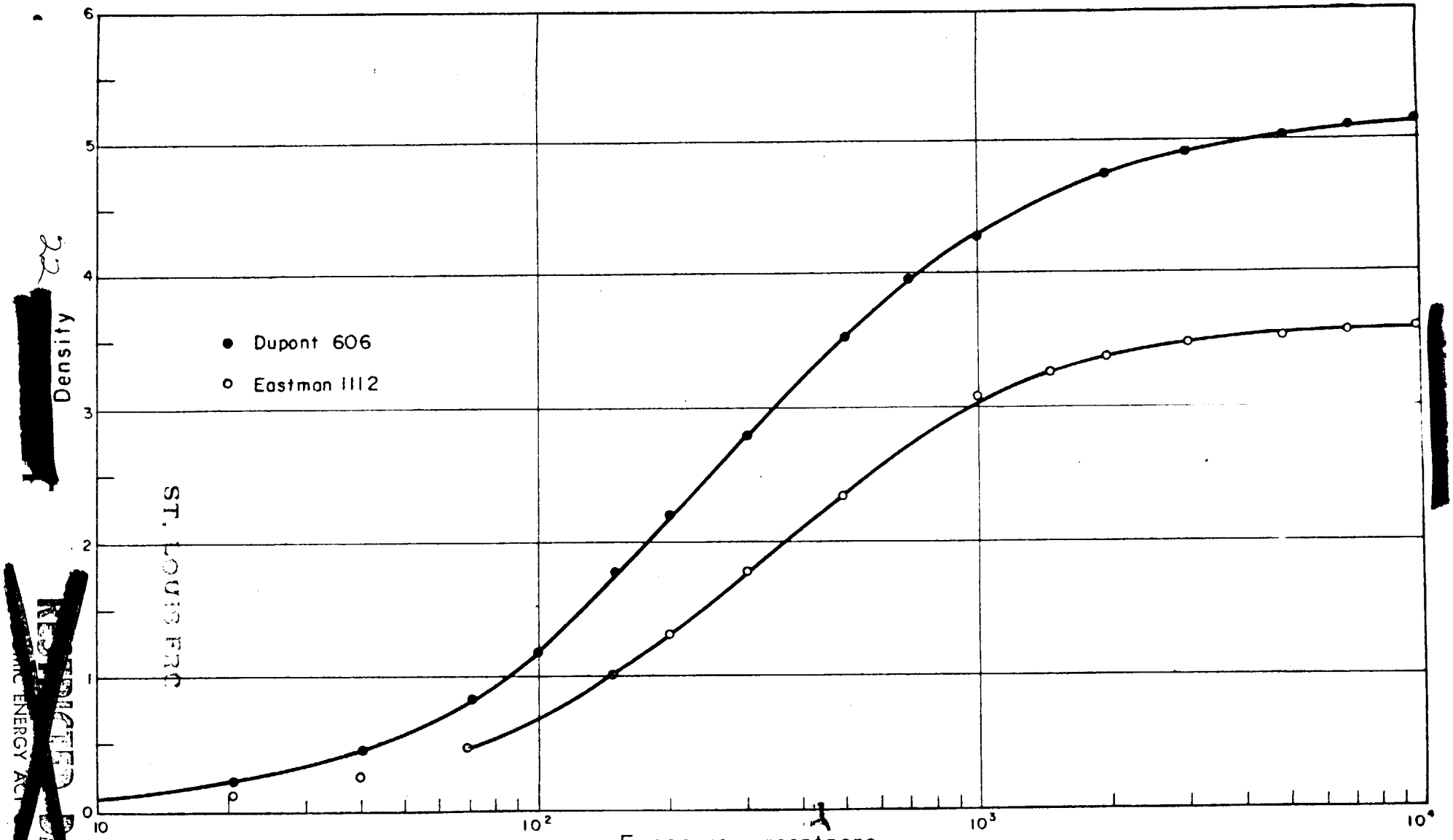

Figure 2.2 Co^{60} calibration curves for film types. Film in TLD holder.

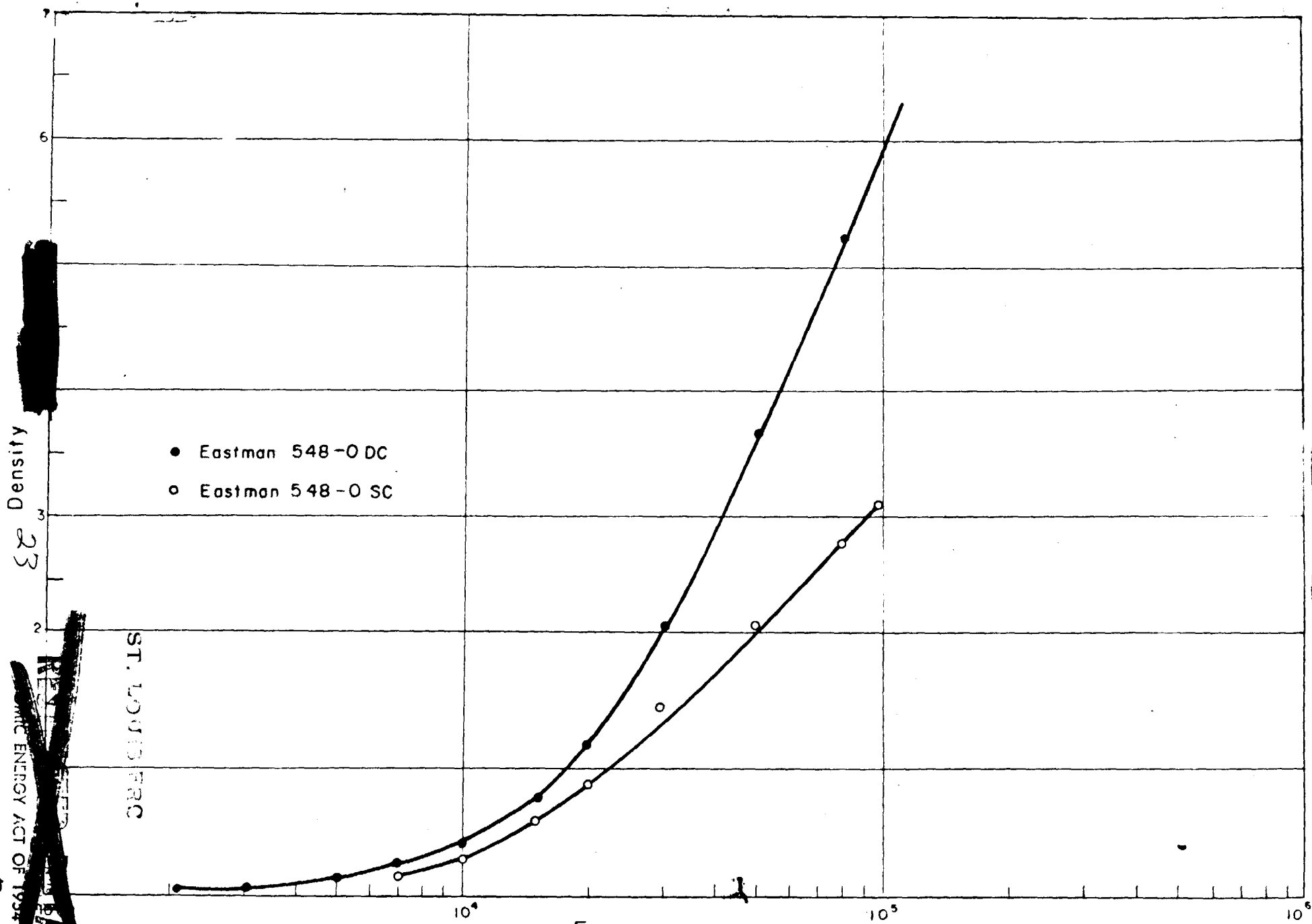

Figure 2.5 Co^{60} calibration curves for film types. Film in FBS holder.

source from 1/2 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 cause variation in density from event to event were the latent image fading of Eastman 548-O 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.

2.2.2 Quarts-Fiber Dosimeters. Seven ranges of quarts-fiber dosimeters, similar to the IM-93/UD evaluated by Teapot Project 6.1.1, were used (References 16 and 17). These dosimeters were calibrated with the Co^{60} source and a correction was made on all readings. They were checked for leakage and faulty ones were eliminated. 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

[redacted]

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).

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

Evaluation of overexposures (pH 5.6 or below) are determined by the titration of the acid formed per millimeter of chlorinated hydrocarbon with standardized 10^{-3} Normal NaOH. The amount of base required to return the overlaying acidimetric dye to its preirradiation pH value is 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 milliliter of chlorinated hydrocarbon per roentgen (absorbed) and division of these values into the acid produced by the unknown exposure yields the gamma doses in roentgens. 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 rest 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, and these were exposed to Shots Flathead and Navajo. Those exposed to

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less than 600 r were read on site, whereas the ones exposed to larger doses were read and evaluated at the Naval Medical Research Institute. (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 is a military standard, field-type, portable instrument used for detecting and measuring gamma exposure rates (Reference 24).

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 2.3 and 2.4). 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.

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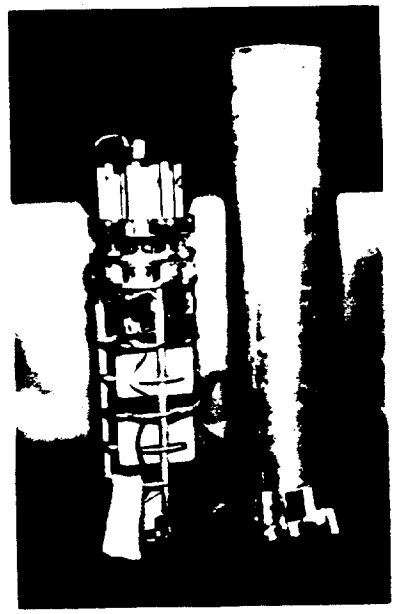

Figure 2.3 Quartz fiber rate device with dosimeters.

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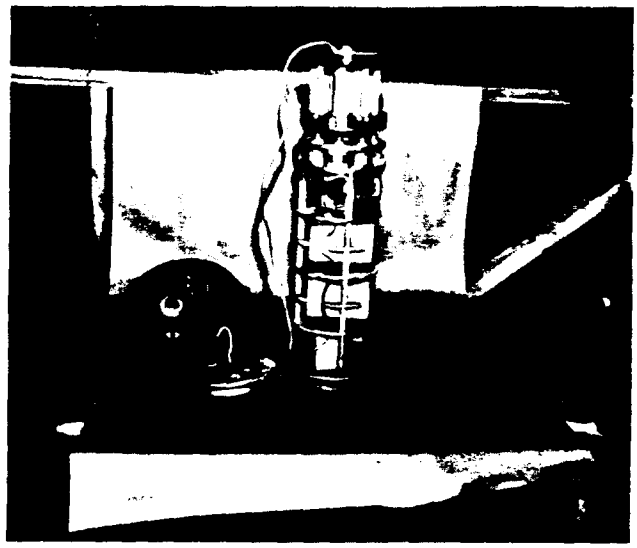

Figure 2.4 Quartz fiber rate device with dropping mechanism.

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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" high and 7-1/2" 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 upon the melting of an eutectic element by thermal radiation. The eutectic element consists 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 is estimated at 1/2 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 1/2 second after the detonation. A second set of dosi-

[redacted]

[redacted]

meters was suspended by a wire from a piece of angle iron on the 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 of the station and another at the bottom.

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, and 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 is of importance in the data analysis.

Series Z10 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 of each end of the cylinder.

Series Z10, Z11, Z12, and Z13 stations were constructed of steel pipe capped at both ends. The pipes were mounted vertically in the ground with the exception of Series Z12, where the pipes were mounted vertically in the center of a 6-foot concrete cube, the surface of which was flush with the ground.

[redacted]

TABLE 2 [illegible] TILIZATION

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

Station Number	Location	Cherokee	Zuni	Flathead	Dakota	Navajo	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					

[redacted]

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	

[redacted]

[redacted]

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.

2.2.9 Co^{60} Field Calibration. Exposures were made with a well-calibrated 4π, 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 inches. 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 inches. 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 22°C 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.

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-

[redacted]

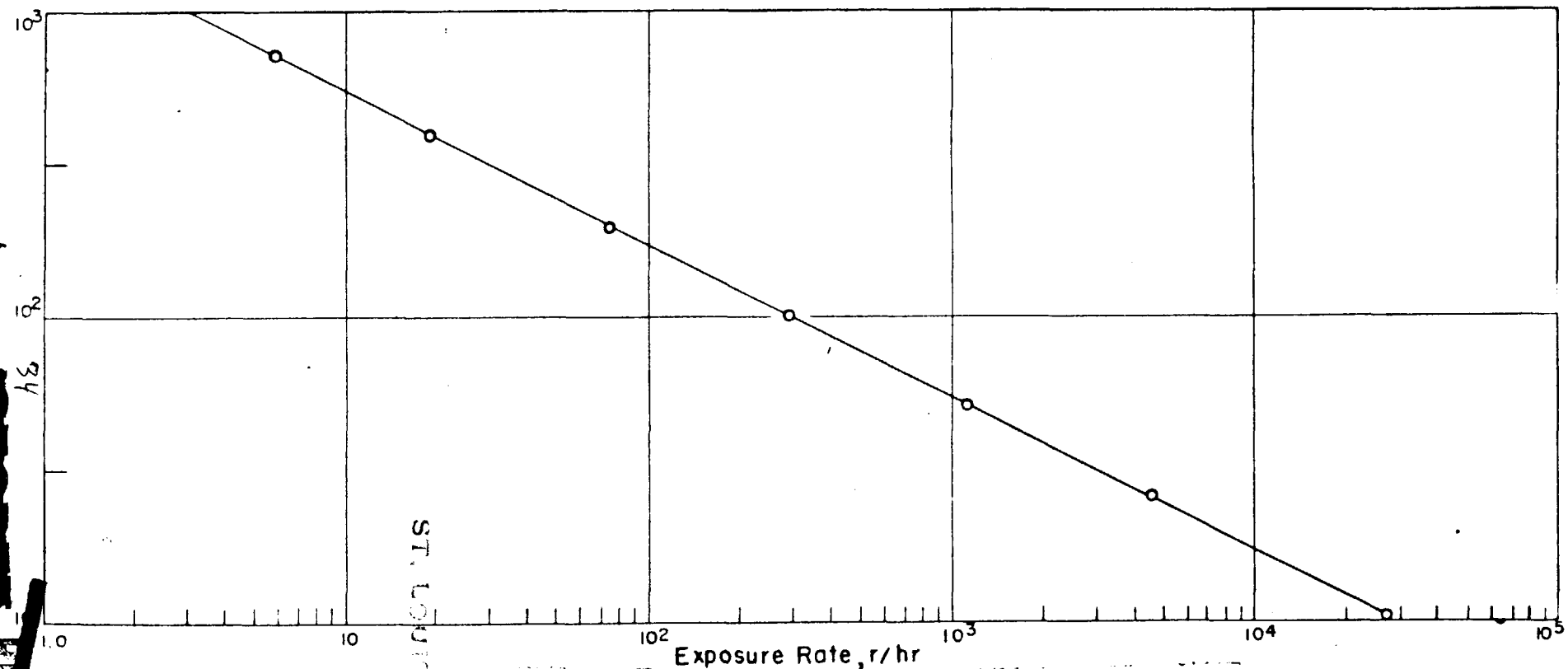

Figure 2.6 200 curie Co^{60} calibration curve.

[redacted]

yield thermonuclear devices detonated at Bikini Atoll. In order that a true measure could be made of initial gamma radiation, a requirement of the measurements was to enable separation of initial from residual gamma radiation.

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 effects of the residual gamma field.

The initial exposure values, after correction for betatron calibration and shielding effects, are accurate to within 30 percent, including errors due to calibration, readout, directional response of the film, and processing. This accuracy percentage is based on previous experience. 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

[redacted]

[redacted]

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 obtain correction factors, NBS has exposed photographic dosimeters to Co^{60} and to the Naval Ordnance Laboratory 10-Mev betatron on several occasions in the past 5 years (References 2, 3, 4, 15, and 25). Examination of these results shows that the correction factors are a function of the particular photographic emulsion, batch, and age. Based on previous work, the correction factors for the emulsions used during Redwing should probably vary between 0.80 and 1.00.

Air Force Special Weapons Center (AFSWC), in cooperation with Los Alamos Scientific Laboratory (LASL) and Evans Signal Laboratory (ESL) has exposed film to the Godiva bare assembly at Los Alamos in order to study the effects of neutrons on photographic emulsions. Results indicate that the film sensitivity for neutrons is 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: 1) a response to low-energy (thermal) neutrons, and 2) a

[redacted]

response to high-energy neutrons. As far as could be determined from the experiment, the two components are independent and additive. The calibration data for neutron flux was furnished AFSWC by H-2 division at LASL. It was assumed that any perturbation in flux caused by the HMS film holders would be small. Neutron-sensitivity values are 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 are 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 is 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. 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

[redacted]

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
		$n/cm^2/Co^{60}$ r x 10^{-9}	n rep dose/Co^{60} 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

[redacted]

[redacted]

TABLE 2.6 INITIAL-GAMMA-EXPOSURE CORRECTION FACTORS

Station Series	Station Shielding	Mutual Shielding	Combined Quartz Fiber and Chemical Correction Factor	Betatron Film Calibration	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

[redacted]

[redacted]

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 may be reduced by a factor of ten, depending on the water-land geometry and tidal wash. In cases where the estimated residual exposure exceeds the resultant initial exposure, an additional uncertainty factor must be added to the normal accuracy factor.

It is 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 O.D. pipe were used.

[redacted]

[redacted]

The variation of exposure in each instrument set was due primarily to the land-water geometry. Since the station still shields 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 are consistent with experimental results.

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 has been found to be most desirable during previous operations (Reference 4), experimental factors have been evaluated to adjust the film readings to quartz-fiber equivalence. These factors are 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 are considered accurate to within 20 percent because of variations in thickness of blast shielding. Residual exposure data that appear in the individual shot reports are uncorrected. The correction factors are used only in computing information included in Figures 3.4 through 3.7.

2.4 SUPPORT FACILITIES

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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

[redacted]

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	[illegible]
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

[illegible] ST. LOUIS FRC

[redacted]

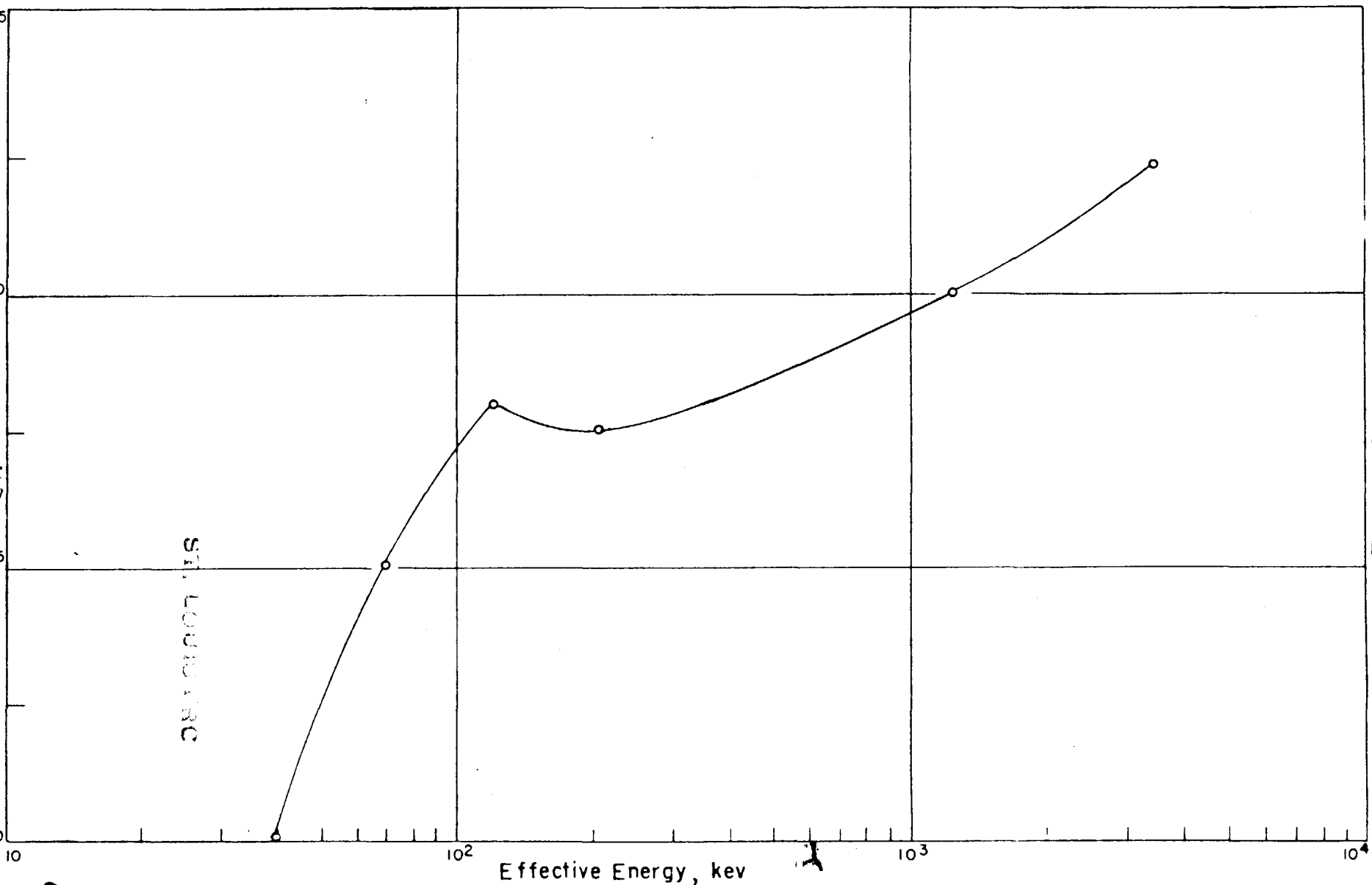

Figure 2.7 DuPont 502 energy dependence curve normalized to Co^{60} value. Film in NBS holder.

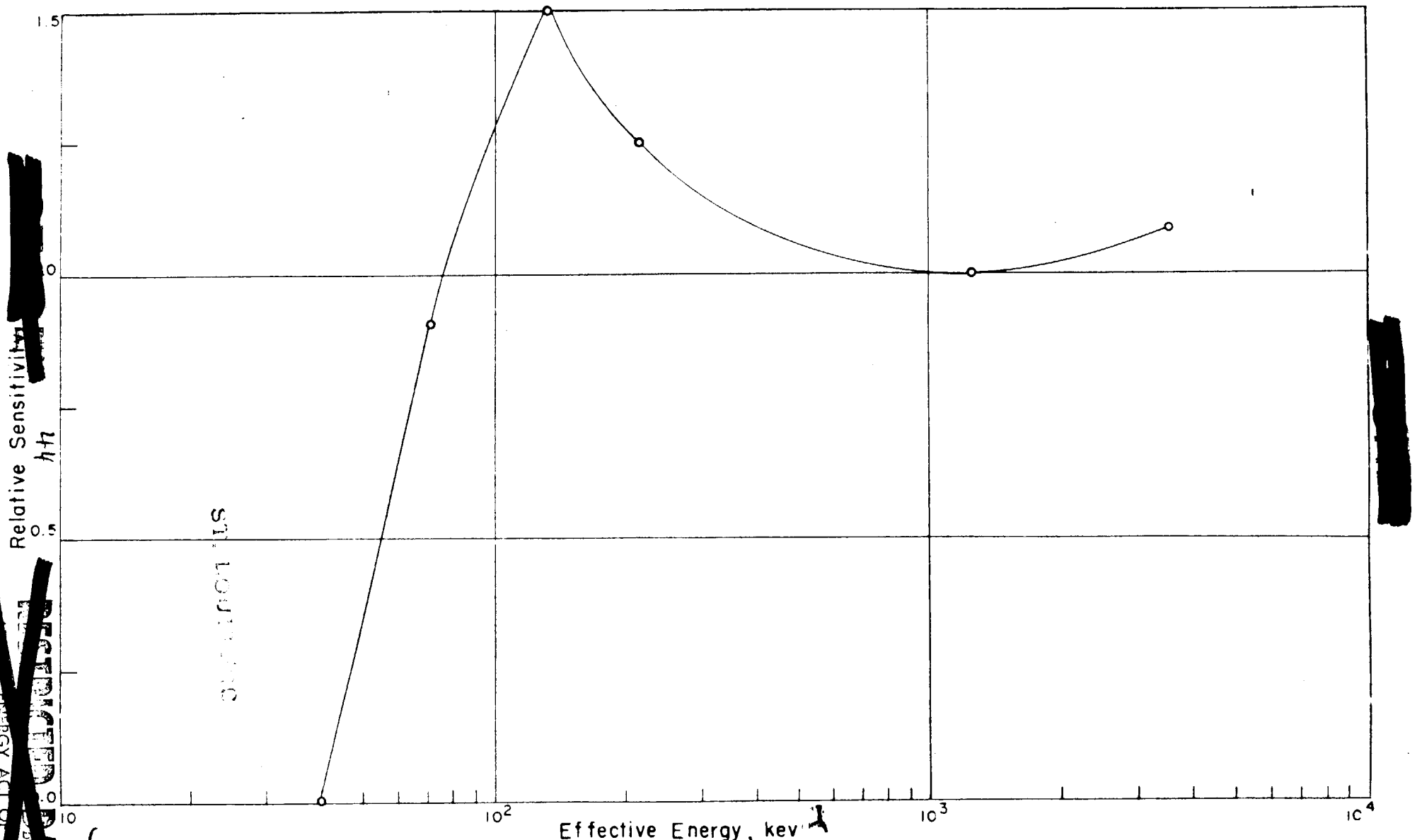

Figure 2.8 DuPont 510 energy dependence curve normalised to Co^{60} value. Film in NBS holder.

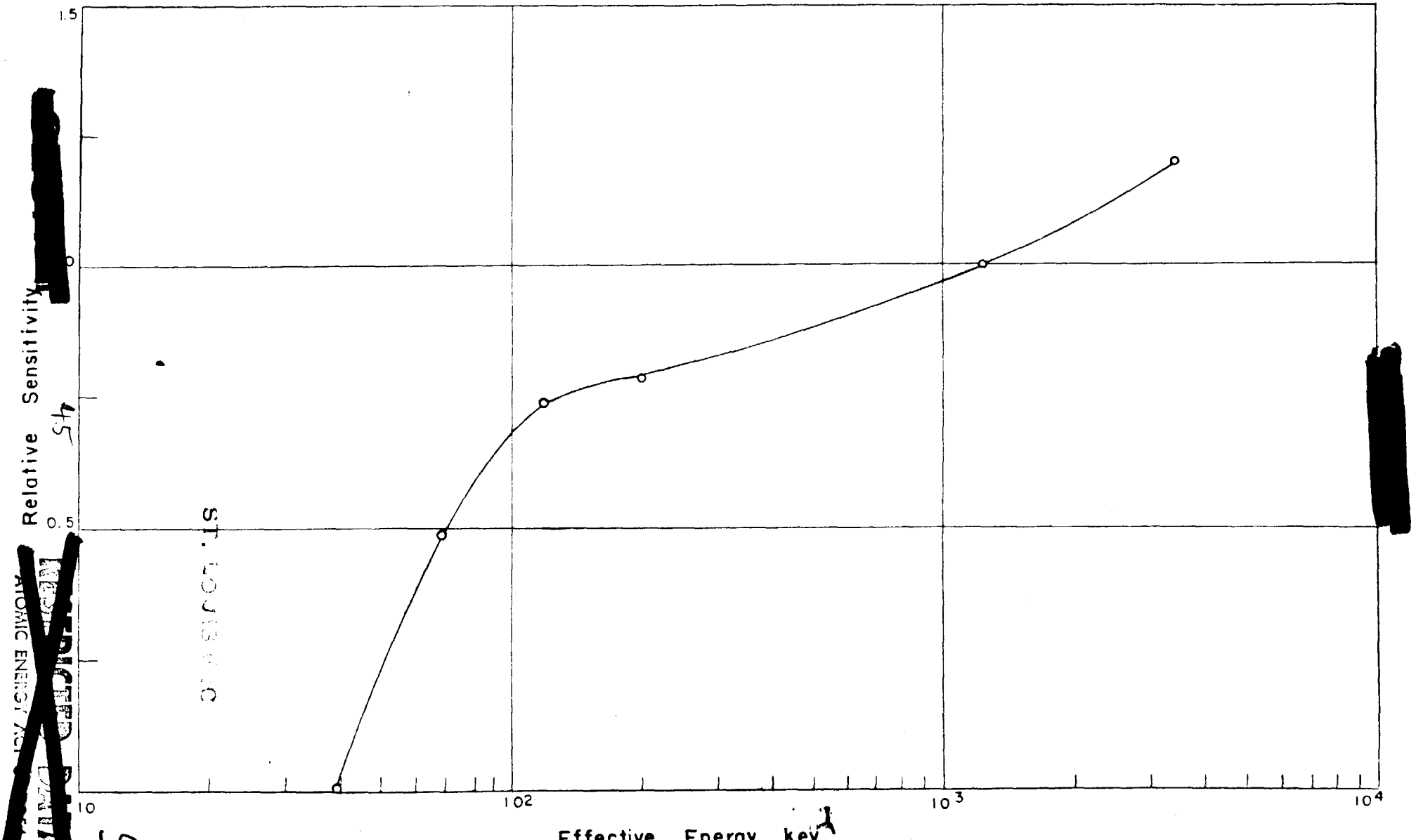

Figure 2.9 DuPont 606 energy dependence curve normalized to Co^{60} value. Film in NBS holder.

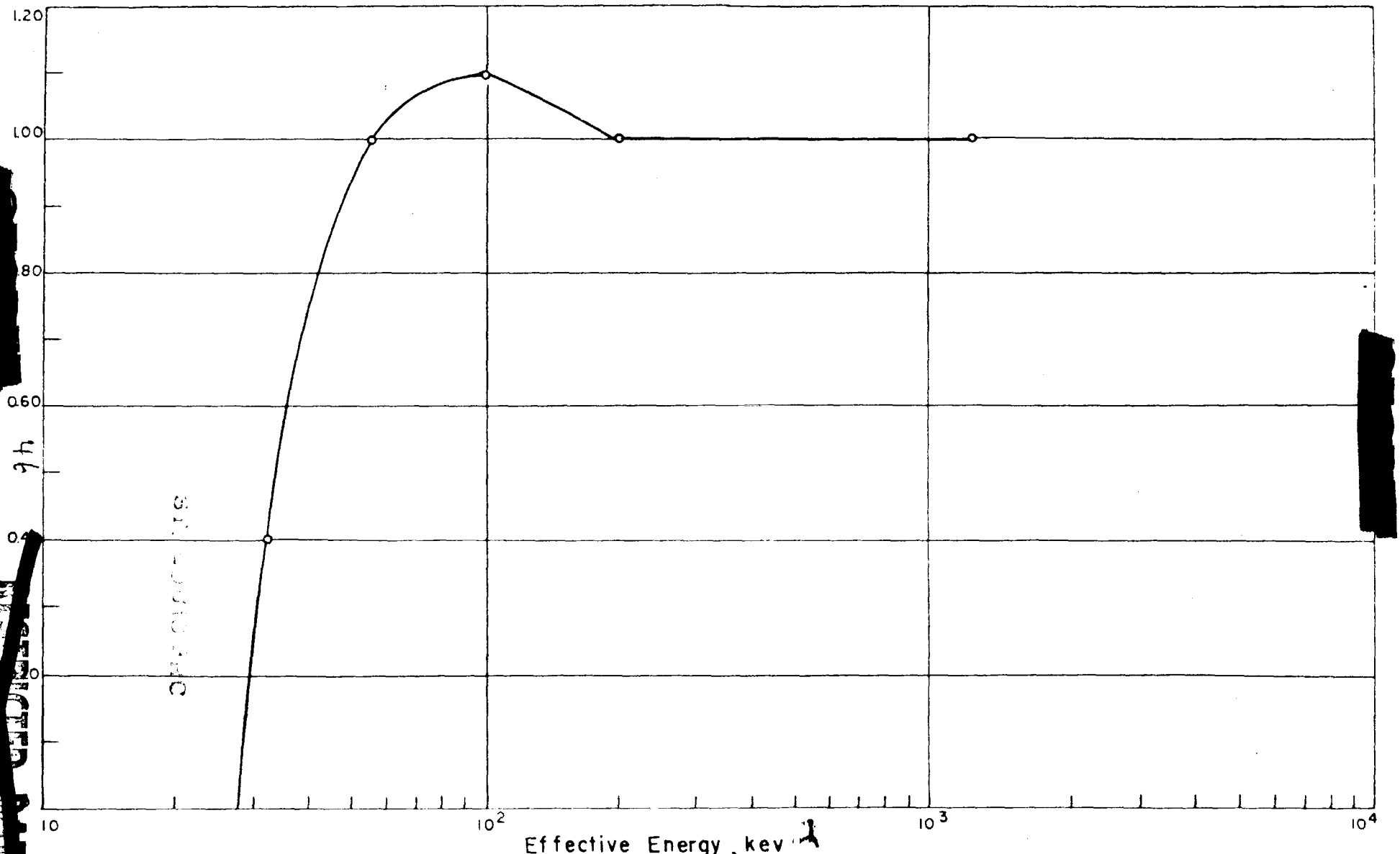

Figure 2.10 Quartz fiber dosimeter energy dependence curve normalised to Co^{60} value.

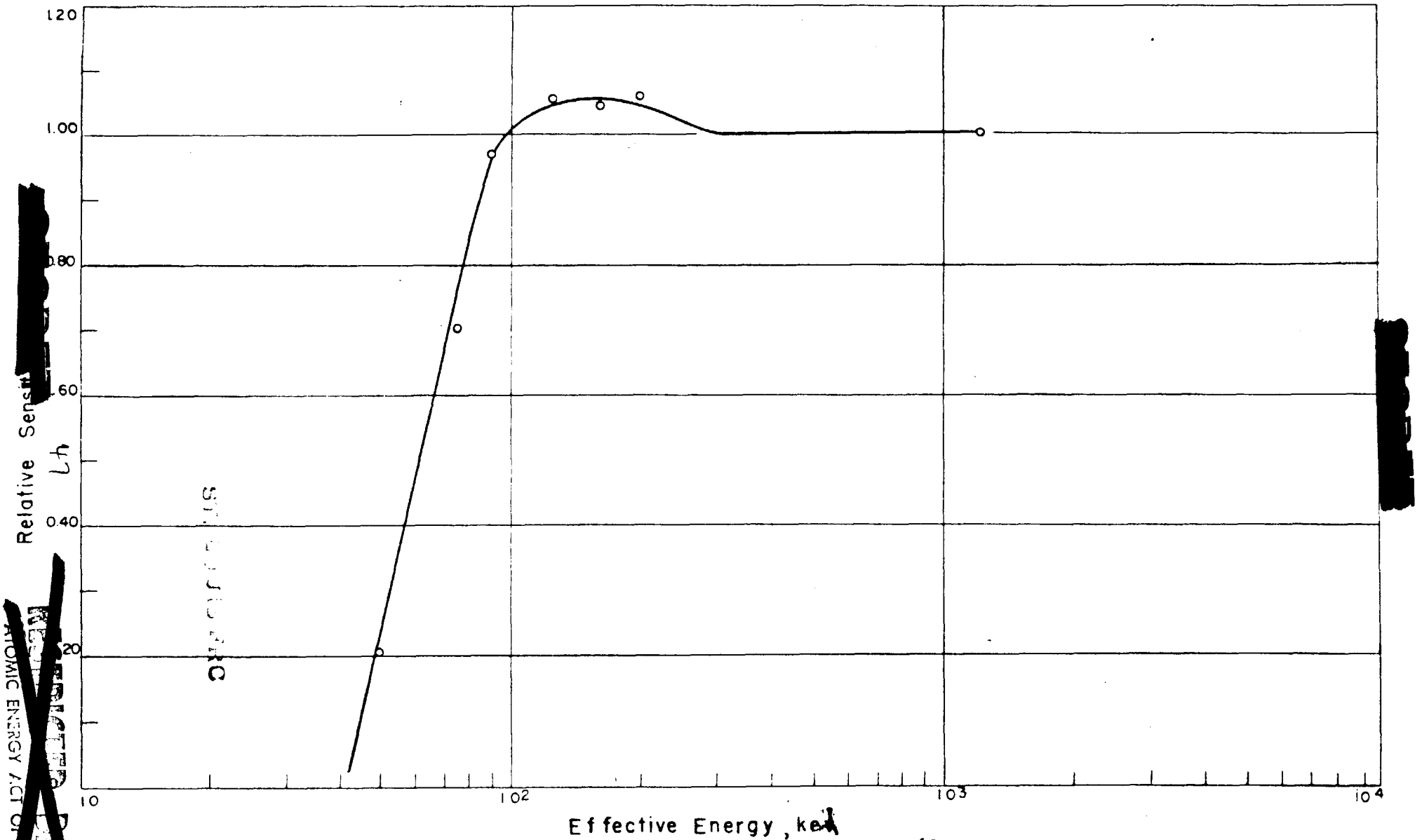

Figure 2.11 AN/PDR-39 energy dependence curve normalized to Co^{60} value.

[redacted]

processed and the results returned to the interested projects. Instruments were exposed to the 200-curie, 4" Co^{60} source, and an 80-curie, collimated Co^{60} source for Projects 2.63, 2.65, 2.66, 2.8, and 4.1.

[redacted]

[redacted]

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 8,000 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 50 mr. Film at the Series 250 and 251 stations was damaged by water or sulphur fumes from damaged neutron-threshold detectors, and therefore the

[redacted]

[redacted]

TABLE 3.1 CHEROKEE DATA

Station Number	Location	Slant Distance	Exposure in NBS Holder	Exposure no NBS Holder
		ft	r	r
112.01	Charlie	19,980		
113.01	C-D Reef[a]	18,360		
113.02	C-D Reef[a]	17,860		
113.03	C-D Reef[a]	17,100	DELETED	
113.04	C-D Reef[a]	17,300		
113.05	C-D Reef[a]	17,970		
113.06	C-D Reef[a]	19,120		

[a]Charlie-Dog

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[redacted] RESTRICTED DATA
ATOMIC ENERGY ACT OF 1954

[redacted]

TAB[illegible] OSURE

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	300	202	221	237
212.02	Charlie	31 May	0920	600	155	135	200
212.03	Dog	31 May	0915	1200	185	195	262
212.04	Easy	31 May	0910	1200	152	185	
212.05	Fox	31 May	0905	1200	207	222	
212.06	George	31 May	0900	1200	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	Destroyed					
210.26[a]	Peter Reef	31 May	1030	50	25		<50
210.26[a]	Peter Reef	31 May	1030	50	69		75
210.27[a]	Peter	29 May	1315	1200	200		220
210.27'[a]	Peter	29 May	1315	1200	102	136	125
210.29	Roger	7 June			2500		
210.30[a]	Roger	29 May	1300	1300	16000		
210.31	Roger	Destroyed					
210.32	Uncle	Destroyed					
210.33[a]	Uncle Reef	30 May	1300	50	1800		850
210.34[a]	Uncle	29 May	1230	1000	465		[illegible]
210.34'[a]	Uncle	29 May	1230	1000	335	368	
210.35[a]	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

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

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TABLE 3.3 ZUNI INITIAL-GAMMA EXPOSURE

All of the data in this table are from film at aluminum stations except those referred to in [a] and [b].

Station Number	Location	Distance	Total Exposure	Estimated Residual Exposure	Resultant Initial Exposure
		ft	r	r	r
210.30	Roger	7000	16000	150	15850
210.29	Uncle Reef	8500	2500	15	2485
210.33	Uncle Reef	9420	1880	15	1785
210.33	Uncle Reef	9420	850[a]	15	835
210.34	Uncle	10320	465	150	315
210.35	Uncle Reef	10935	205	15	190
210.27	Peter	11270	200	150	50
210.27'	Peter	11270	145[b]	100	45
210.56	Peter Reef	11510	69	15	54
210.26	Peter Reef	12940	25	15	10

[a]These data are from a chemical dosimeter.
[b]These data are from a quartz fiber exposure versus time device in a steel station.

[redacted]

[redacted]

results are not included.

The exposures at the stations listed in Table 3.1 are possibly from initial gamma radiation. Temperature effects on the film could have caused an increase in background density. The presence of low-energy gamma components in the residual field are indicated by the higher exposures measured by films exposed without NBS holders. The instrumentation and recovery rates were negligible.

3.3 SHOT ZUNI

See Tables 3.2 and 3.3. 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 initial gamma readings were obliterated by the residual radiation. The cap of 210.30' was broken by the shock, and the instruments fell immediately.

DELETED

A third rate device at 210.34' without a dropping mechanism yielded only total exposure information.

A mechanical drop device installed in a water-filled steel pipe at 210.23' functioned properly. All of the films that dropped read less than 1 r, since the initial exposure was negligible.

3.4 SHOT FLATHEAD

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See Tables 3.4 and 3.5. The disparity between the film and quartz-fiber exposures at Station 212.03 is not fully understood. At Station 212.05 the 10-r thermal and blast exposures are the result of residual contamination from Shot Zuni. Film indicates about [redacted] initial exposure, and quarts-fiber dosimeters indicate about [redacted] The switches in the

DELETED

[redacted]

RESTRICTED DATA

ATOMIC ENERGY ACT OF 1954

[redacted]

TABLE 3.4 [illegible] INSTRUMENTATION AND RECOVERY

Shot time was 0626, 12 Jun[illegible]

Station Number	Location	Instrumentation Date	Instrumentation Time	Instrumentation Rate	Recovery Date	Recovery Time	Recovery Rate
				mr/hr			mr/hr
213.01	MMB	8 June	1350	DELETED	16 June	1430	DELETED
212.03	Dog	6 June	1[illegible]		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	1505	
213.04	Fox	No Record			14 June	1400	
211.04	George	No Record			No Record		
211.06	George	No Record			No Record		

TABLE 3.5 FLATHEAD INITIAL EXPOSURE

Station Number	Location	Position or Timing	Total Exposure Film	Total Exposure Quartz Fiber	Total Exposure Phosphate Glass	Total Exposure Chemical	Total Residual	Initial Exposure	Distance
			r	r	r	r	r	r	ft
212.03	Dog	Thermal Blast 1 Minute Total							4422
213.02	Dog	Total							5110
211.01	Dog	Total Rear							5500
213.03	Dog-Easy	Total							5950
213.01	Man-Made 3	Total							6605
211.02	Dog-Easy	Total Front Rear							6650
212.04	Easy	Total							7720
211.03	Easy-Fox	Total Front Rear							
212.05	Fox	Thermal Blast 1 Minute Total							10745
213.04	Fox	Total							11700
211.04	Fox-George	Total Front Rear							12650
212.06	George	Total							14920

DELETED

[a] Container was shielded after initial exposure. The total residual exposure is estimated at [redacted] See Station 211.02, Table 3.6.

[b] The 10 r for thermal and blast result from residual radiation from Shot Zuni from instrumentation time to detonation time.

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[redacted]

[redacted]

mechanical drop devices at Z13.02, Z13.03, and Z13.04 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 Z11.01 did not drop; therefore it was necessary to subtract the residual exposure of [redacted] At Station Z10.02, 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 Z12.04 operated in reverse, yielding only total residual information. The exposure at Station Z11.03 was small and could not be resolved properly.

Table 3.7 lists installation, recovery, and residual exposure information. Project 2.2 information indicates that Stations Z10.23 to Z10.41 received about 1 r of fallout exposure from this shot, the remainder having come from Shot Zuni.

3.5 SHOT DAKOTA

See Tables 3.8 and 3.9. High residual gamma exposure rates resulted from Shot Flathead at the time of the 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 1/2 mile closer to the Fox complex, the lowest initial exposure recorded was about [redacted]

Dosimeters were placed in two locations on Man-Made Island 3 prior to Shot Flathead. One group of dosimeters was found during Flathead recovery, and the second group was recovered after Dakota. A Dakota

[redacted]

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[redacted]

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[redacted]

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[redacted]

DELETED

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

[redacted]

[redacted]

[redacted]

TABLE 3.9 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					4422
211.01	Total Blast					5500
213.01	Total		DELETED			6605
211.02	Total Blast					6650
212.04	Total 1 minute					7220

[a]This result was obtained by subtracting the 1-minute value from the total value. The other estimates were based on this value.
[b]This result was obtained by subtracting the total Flathead exposure [redacted] from the Flathead plus Dakota exposure [redacted]

[redacted]

[redacted]

[redacted]

data point was obtained by subtracting the Flathead exposure.

3.6 SHOT NAVAJO

See Tables 3.10, 3.11, and 3.12. Some phenomenon, perhaps the shock, caused all of the quartz-fiber dosimeters in the rate devices to activate at an early time. As a result, they yielded only total exposure data. Station 211.01 was partially blown out of the ground. The rate device did not drop, thus the station yielded only total exposure information. The 1-minute drop timers were corroded and did not function. Consequently, the estimates of residual exposure on Sites Dog and Easy are not accurate.

3.7 SHOT TEWA

Table 3.13 gives 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 are well established. Residual exposure estimates were obtained from Stations 113.02 and 113.03. These stations were in the same general area and had the same geometry and recovery rates, but they 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 appears valid. The chemical data at 113.08 is probably in error, since it contradicts both the film data at 113.08 and the chemical data at 113.04, and is far below the predicted level. The exposures anticipated 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

[redacted]

[redacted]

TABLE 3.10 NAVAJO INSTRUMENTATION AND RECOVERY

Shot time was 0556, 11 July 1956

Station Number	Location	Instrumentation			Recovery		
		Date	Time	Rate	Date	Time	Rate
210.19	Fox	7 July	1530				
210.20	George	7 July	1540				
210.23	Oboe	5 July	0750				
210.27	Peter	5 July	0755				
210.30	Roger	5 July	0800				
210.34	Uncle	5 July	0808				
210.37	William	5 July	0815				
210.38	Yoke	5 July	0822				
210.39	Zebra	5 July	0827				
210.40	Alfa	5 July	0832				
210.41	Bravo	5 July	0835				
212.01	Able	5 July	0848				
212.02	Charlie	5 July	0857				
113.07	M M No. 1	5 July	0905				
113.08	M M No. 2	5 July	0910				
113.09	M M No. 3	5 July	0920				
212.03	Dog	7 July	1420				
212.04	Easy	7 July	1230				
212.05	Fox	7 July	1125				
212.06	George	7 July	1000				
211.01	Dog	7 July	1400				
211.02	Dog-Easy	7 July	1335				
211.03	Easy-Fox	7 July	1340				
211.04	Fox-George	7 July	1020				
213.02	Dog	7 July	1410				
213.04	Fox	7 July	1040				

DELETED

[redacted]

TABLE 3.11 NAVAJO INITIAL-GAMMA EXPOSURE

Station	Distance	Timing or Position	Total Dose				
			Film	Quartz Fiber	Phosphate Glass	Residual	Initial
	ft		r	r	r	r	r
212.03	7922	rear					
		blast					
		thermal					
		down					
212.04	10680	total					
212.05	13180	total					
		1 minute					
		rear					
212.06	16180	total					
		rear					
211.01	8960	total					
211.02	9810	total					
211.03	11880	total					
		1 minute					
211.04	14750	total					
		blast					
		thermal					
		down					
		rear					
213.02	8580	total					
213.04	13820	total					
		blast					
		thermal					
		down					
		rear					
M M 1	16190	total					
M M 2	12900	total					
M M 3	DESTROYED						
210.19	14250	total					
210.20	16600	total					

DELETED

[a] Estimate
[b] Dose contributed entirely by residual radiation.

TABLE 3.12 NAVAJO RESIDUAL EXPOSURE

Station	Position	Film	Phosphate Glass	Quartz Fiber
		r	r	r
212.01	Inside	105	152	115
	Outside	170		
212.02	Inside		53	40
	Front	79		
	Right	99		
	Rear	37		
	Left	32		
210.23	Inside	2.2		2.2
	Outside	2.2		
210.27	Inside	2.7		3.4
210.30	Inside	3.4		3.8
210.34	Inside	1.7		3.8
	Outside	1.8		
210.37	Inside	2.8		6.4
210.38	Inside	4.2		4.5
210.39	Inside	7.4		8
210.40	Inside	8		8
210.41	Inside	8.3		11
	Outside	6.9		

[redacted]

TABLE 3.13 EDWA INSTRUMENTATION AND RECOVERY
(Shot time, 0546, 21 July 1956)

STATION	LOCATION	POSITION	INSTRUMENTATION DATE	INSTRUMENTATION TIME	INSTRUMENTATION RATE	RECOVERY DATE	RECOVERY TIME	RECOVERY RATE
					mr/hr			mr/hr
E12.01	Able	Front	15 Jul	1010	90	24 Jul	1420	4000
		Right			90			
		Rear			90			
		Left			90			
E12.02	Charlie	Front	15 Jul	1000	32	24 Jul	1425	3000
		Right			47			
		Rear			38			
		Left			27			
113.01	Charlie-Dog Reef		16 Jul	1645	4	25 Jul	1750	8
113.02	"		16 Jul	1625	3	25 Jul	1755	20
113.03	"		16 Jul	1600	3	25 Jul	1810	40
113.04	"		16 Jul	1510	4	25 Jul	1825	18
113.05	"		16 Jul	1440	0 [illegible]	25 Jul	DESTROYED	
113.07	MM Mr 1		16 Jul	1400	90	25 Jul	1100	1000
113.08	MM Mr 2		16 Jul	1250	120	24 Jul	1430	2800
113.09	MM Mr 3		16 Jul	1200	80	25 Jul	1115	3500
E12.03	Dog	Front	15 Jul	0945	80	25 Jul	0930	1500
		Right			100			
		Rear			100			
		Left			70			

[redacted]

[redacted]

TABLE 3.13 TEWA INSTRUMENTATION AND RECOVERY - continued -

STATION	LOCATION	POSITION	INSTRUMENTATION DATE	INSTRUMENTATION TIME	INSTRUMENTATION RATE	RECOVERY DATE	RECOVERY TIME	RECOVERY RATE
					mr/hr			mr/hr
Z12.04	Easy	Front	15 Jul	0950	60	24 Jul	1050	2400
		Right			80			
		Rear			100			
		Left			60			
Z12.05	Fox	Front	15 Jul	0935	60	24 Jul	1110	3000
		Right			65			
		Rear			70			
		Left			60			
Z12.06	George	Front	15 Jul	0925	30	24 Jul	1120	1000
		Right			45			
		Rear			70			
		Left			45			
Z10.23	Oboe		15 Jul	1105	8	24 Jul	1320	6
Z10.27	Peter		15 Jul	1100	4	24 Jul	1330	8
Z10.30	Roger		15 Jul	1056	9	24 Jul	1335	18
Z10.34	Uncle		15 Jul	1047	4	24 Jul	1342	220
Z10.37	William		15 Jul	1038	8	24 Jul	1350	1000
Z10.38	Yoke		15 Jul	1033	5	24 Jul	1355	1000
Z10.39	Zebra		15 Jul	1030	9	24 Jul	1400	1500
Z10.40	Alfa		15 Jul	1025	8	24 Jul	1402	2200
Z10.41	Bravo		15 Jul	1020	7	24 Jul	1404	2200

[redacted]

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[redacted]

[redacted] ENERGY ACT OF [illegible]

[redacted]

TABLE 3.14 TRWA 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	1300		1045	
210.41	825		755	
212.01	2300		2833	front
			1916	right
			3016	rear
			2400	left
212.02	890		823	
	2650	rear	1000	front
			1485	right
			1460	rear
			940	left
212.03	695		610	
	1102	rear	580	front
			920	right
			860	rear
			762	left
212.04	510		375	
212.05	521		399	
	1027	rear	700	front
			710	right
			668	rear
			640	left
212.06	240		201	

[redacted]

TABLE 3.15 TEWA INITIAL-GAMMA EXPOSURE

STATION	DISTANCE, ft	TOTAL DOSE, r FILM	CHEMICALS	ESTIMATED RESIDUAL, r	INITIAL, r
113.01	15,890	160	250	160 to 250	
113.02	14,380	250	250	250	
113.02	14,380[a]	400	---	400	
113.02	14,380[a]	580	---	580	
113.02	14,380[a]	820	---	820	
113.03	10,500	3,300	2,500	250	2,650
113.04	6,760	> 70K	3.35×10^5	250	3.35×10^5
113.05		DESTROYED			
113.06		DESTROYED -- NOT INSTRUMENTED			
113.07	2,875	> 70K	6.5×10^5[b]	800	Very great
113.08	5,940	> 70K	42,000[c]	800	> 70K
113.09	10,830	1,950	---	800	1,150

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

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

[c] 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.

[redacted]

exposure was much greater than 650,000 r. There is no sound explanation for discrepancies that occur in the chemical data derived from 113.07 and 113.08, and thus the reliability of the data from 113.04 becomes questionable.

It is felt that the initial exposure data from 113.03 is reliable since the total exposure was well established and the residual estimate was valid. Data from Stations 113.03, 113,04 and 113.09 agree with results from previous events.

3.8 DISCUSSION

Table 3.16 summarizes 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. Cherokee data were adjusted to relative air density of 0.895. The initial gamma exposure from Cherokee, Zuni, and Navajo at 3 miles was about 1 r. The accuracy of the initial gamma exposure data as corrected is within ± 30 percent.

Figures 3.5 through 3.8 show the total residual gamma exposures plotted on maps. These exposures are corrected for station shielding and spectral response of the dosimeters (Section 2.3.2). In addition, all of the values from a given shot were adjusted to the same recovery time

[redacted]

TABLE 3.16 MEDWING INITIAL-GAMMA EXPOSURE

EVENT	STATION	UNCORRECTED INITIAL, r	COMBINED CORRECTION FACTOR	CORRECTED INITIAL, r	DISTANCE, ft
Cherokee[a]	113.03				17,100
	113.04	DELETED			17,300
	113.05				17,970
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
	210.36	54	1.0	54	11,510
	210.26	10	1.0	10	12,940
Flathead	212.03				4,422
	213.02				5,110
	211.01[b]				5,500
	213.03				5,950
	213.01				6,605
	211.02[b]				6,650
	212.05	DELETED			10,745
Dakota	212.03				4,422
	211.01				5,500
	213.01				6,605
	211.02				6,650

[redacted]

TABLE 3.16 REDWING INITIAL-GAMMA EXPOSURE - continued -

EVENT	STATION	UNCORRECTED INITIAL, r	COMBINED CORRECTION FACTOR	CORRECTED INITIAL, r	DISTANCE, ft
Dakota (contd)	212.04				7,720
Navajo	212.03				7,922
	213.02				8,580
	211.01[b]	DELETED			8,960
	211.02[b]				9,810
	212.04				10,680
	211.03[b]				11,880
	212.05[b]				13,180
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

[a]Cherokee exposure adjusted to 0.895 relative air density.

[b]Station contained a rate device.

[redacted] RESTRICTED [redacted]

[redacted]

TABLE 3.17 YIELDS AND RELATIVE AIR DENSITIES

EVENT	TOTAL YIELD, Mt	FISSION YIELD	RELATIVE AIR DENSITY
Cherokee			0.847
Zuni	3.53		0.894
Flathead			0.896
Dakota	DELETED		0.893
Navajo			0.895
Tewa	5.01		0.893

[redacted]

[redacted]

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Figure 3.2 Initial gamma exposure versus distance for Cherokee and Fund.

[redacted] 10^3 [redacted] DATA

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[redacted]

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Figure 3.3 Initial gamma exposure versus distance for Flathead, Dakota, and Navajo.

70 Distance 10^3 feet

[redacted]

[redacted]
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Figure 3.4 Initial plume exposure versus distance for Navajo and Texa.

[redacted]

[redacted]

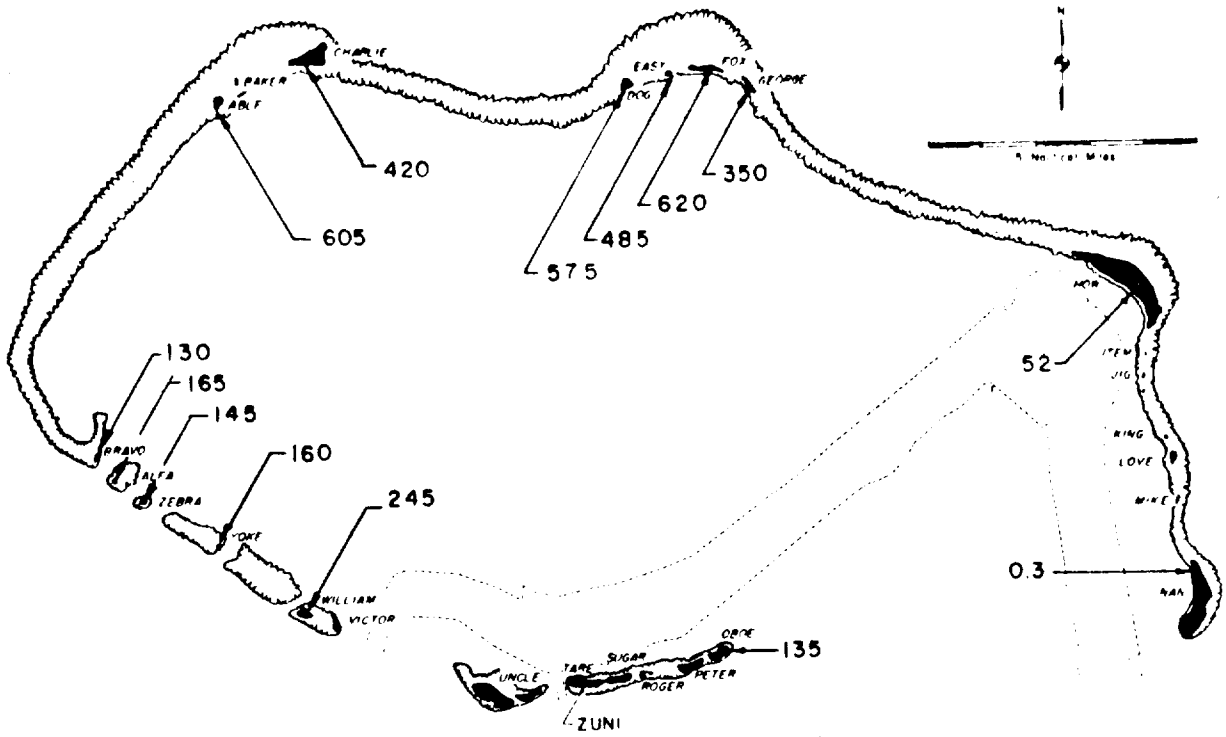

Figure 3.5 Zuni 76-hour residual exposure (roentgens)

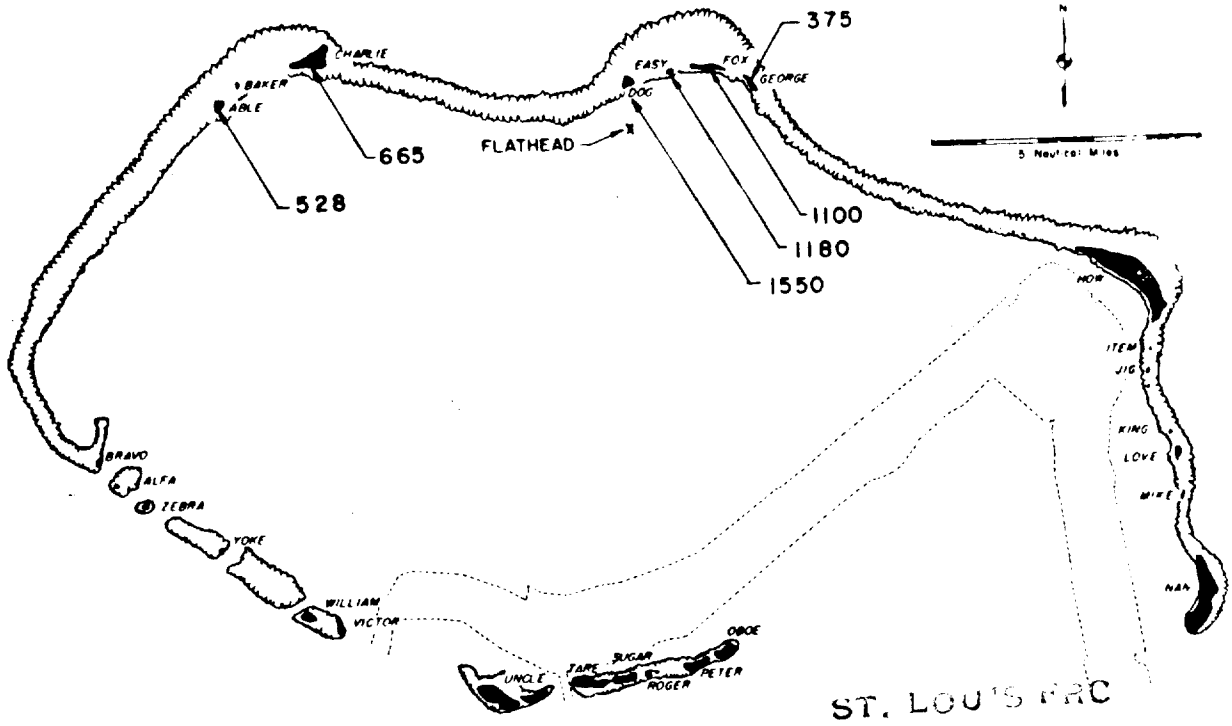

Figure 3.6 Flathead 72-hour residual exposure (roentgens)

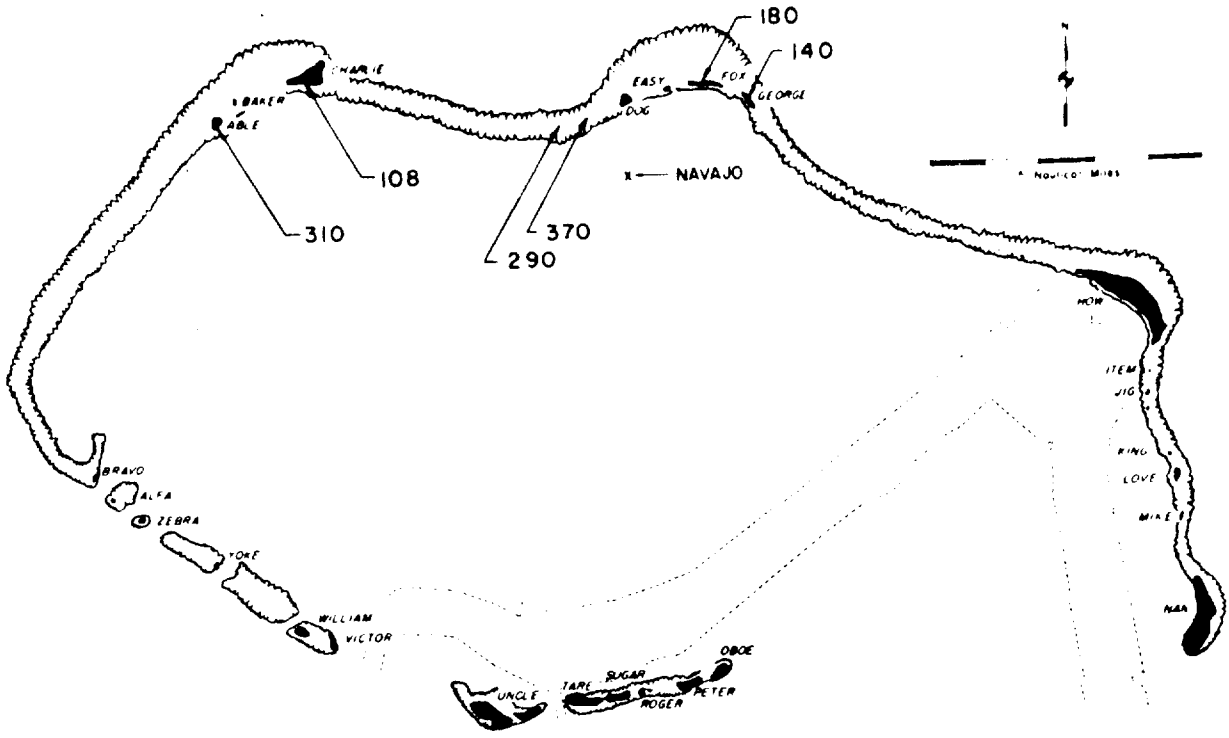

Figure 3.7 Navajo 48-hour residual exposure (roentgens)

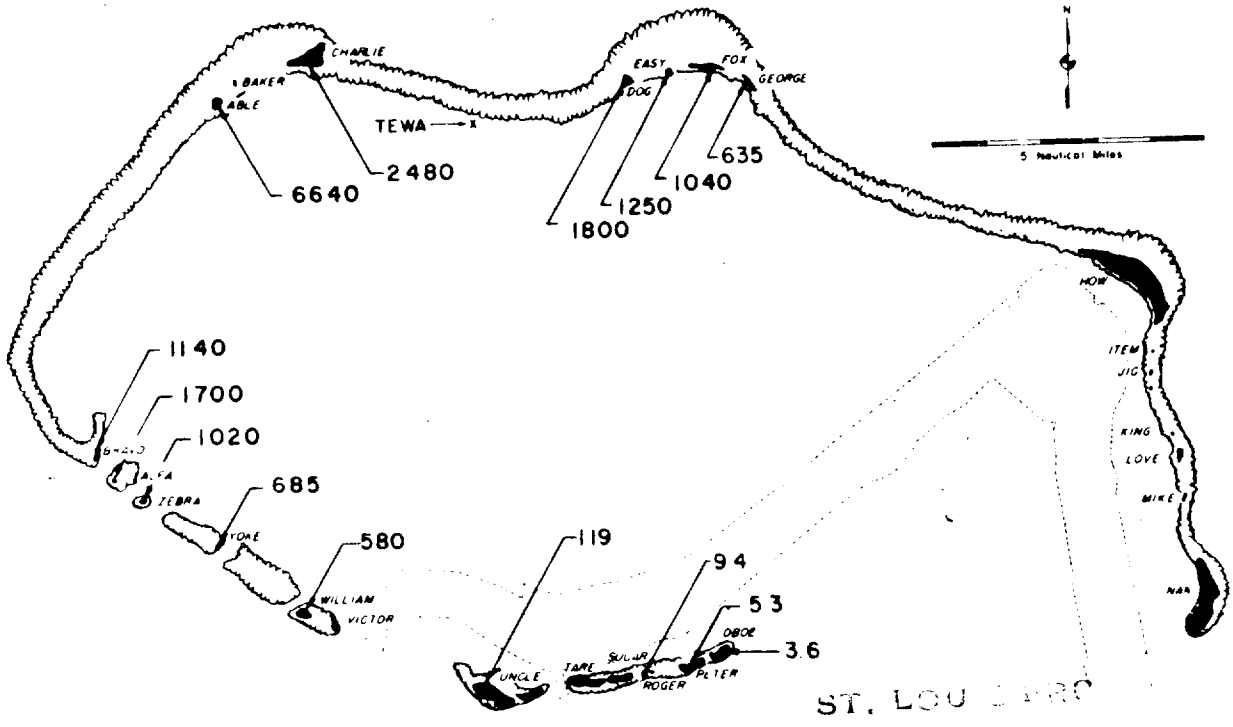

Figure 3.8 Tewa 78-hour residual exposure (roentgens)

[redacted]

using recovery rates, and assuming a decay exponent of -1.2. Individual stations, such as the one on Site Charlie, may show a reduced amount of exposure because it is near the lagoon. The accuracy of the residual gamma data presented in this section is within ±50 percent.

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 weapons. It is felt that the objectives of the project were met, with the exception of Shot Cherokee (for which insufficient data were obtained to form definite conclusions).

In the case of 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 between 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.

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.

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CHAPTER 4

CONCLUSIONS

Examination of the data indicates the following conclusions:

1. For surface bursts with yields [redacted] to 5 Mt, and for a 4300-foot high [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. At long ranges, Project 2.1 data are below the predicted data, whereas at shorter ranges, the field data crosses over and the reverse is true. This variation between predicted and field data increases with increasing yield.

[redacted]

[redacted]

REFERENCES

1. Capabilities of Atomic Weapons; TM 23-200, prepared by AFSWP; OPNAV INSTRUCTION 003400.1A, AFL 136-4, NAVMC 1104, Department of the Army, the Navy and the Air Force, revised edition, 1 June 1955 with changes of 1 April 1956; SECRET-RD.

2. Dempsey, R. H., Larrick, R. G., and Baraff, G. A.; Gamma Radiation Dosimetry; Project 2.1, Operation Castle, WT-912, May 1954; U. S. Army Signal Engineering Laboratories, Fort Monmouth, New Jersey; SECRET-RD.

3. Graham, J. B., and others; Gamma Exposure Versus Distance; Project 2.1, Operation Teapot, WT-1115, May 1955; USASEL, Fort Monmouth, New Jersey; SECRET-RD.

4. Larrick, R. G., Johnson, O. E., and Marmiroli, R. G.; Initial Gamma Exposure Versus Distance; Project 6.8a, Operation Upshot-Knothole, WT-756, April 1955; USASEL, Fort Monmouth, New Jersey; SECRET-RD.

5. Malik, J. S.; Gamma Radiation Versus Time; Projects 5.1 and 5.2, Operation Ivy, WT-634, November 1952; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; SECRET-RD.

6. Harris, P. S., Hurst, G. S., Rossi, H. H., Sigoloff, S. C., and Langham, W. H.; Physical Measurement of Neutron and Gamma Radiation Dose from High Neutron Yield Weapons and Correlation of Dose with Biological Effect; Project 39.7, Operation Teapot, ITR-1167, April 1955; SECRET-RD.

7. Gamma Radiation Measurements; Operation Jangle, WT-370, April 1952; SECRET-RD.

8. Schorr, M. G., and Gilfillan, E. S.; Predicted Scaling of Radiological Effects to Operational Weapons; Project 2.0, Operation Jangle, WT-391, June 1952; Technical Operations, Incorporated, Arlington, Massachusetts; SECRET-RD.

9. Super Effects Handbook; AFSWP 351; May 1952; SECRET-RD.

10. Borg, D. C., and Eisenhauer; Spectrum and Attenuation of Initial Gamma Radiation from Nuclear Weapons; January 1955; Weapons Effects Division; AFSWP 502B; SECRET-RD.

11. Malik, J. S.; Summary of Information on Gamma Radiation from Atomic Weapons; LA-1602, January 1954; Los Alamos Scientific Laboratory; SECRET-RD.

12. Bass, R. C., Smith, L. J., and Ungar, S. H.; Gamma Radiation Spectrum of Residual Contamination; Project 2.2a, Operation Upshot-Knothole, WT-718, May 1955; USASEL, Fort Monmouth, New Jersey; CONFIDENTIAL-RD.

13. Gibson, H. F., and others; Scientific Director's Report, Annex 1.2 - Delayed Gamma-Ray Measurements, Part I - Gamma-Ray Spectrum Measurements; Operation Greenhouse, WT-107 (Ref.), 1951; SECRET-RD.

14. Ehrlich, M.; Photographic Dosimetry of X- and Gamma-Rays; National Bureau of Standards Handbook 57, 20 August 1954.

15. Ehrlich, M.; National Bureau of Standards Report 8A107 and 8A121, Radiation Sensitivity of Photographic Emulsions.

[redacted]

82

16. Johnson, J. M., and Poyet, G.; Evaluation of Military Radiac Equipment; Project 6.8, Operation Upshot-Knothole, WT-755, June 1954; USASEL and Bureau of Ships; CONFIDENTIAL.

17. Cohen, A. E., Jachter, M. H., and Murphy, H. M., Jr.; Evaluation of Military Radiac Equipment; Project 6.1.1a, Operation Teapot, WT-1137, May 1955; USASEL, Fort Monmouth, New Jersey; CONFIDENTIAL-RD.

18. Sigoloff, S. C., Borella, H. M., and Auxier, J. A.; Biological Effects from Massive Doses of Neutron-Gamma Radiation; Dosimetry Report; USAF Report No. 55-108; School of Aviation Medicine.

19. Sigoloff, S. C.; Fast Neutron Insensitive Gamma Ray Dosimeters; The AC and ATCE Systems; School of Aviation Medicine, USAF, In Press.

20. Taplin, G. V., and others; Comparison and Evaluation of Dosimetry Methods Applicable to Gamma Radiation; Project 29.1, Operation Upshot-Knothole, WT-802, September 1953; School of Medicine, Atomic Energy Project, University of California at Los Angeles; CONFIDENTIAL-RD.

21. Taplin, G. V., and others; Measurement of Initial and Residual Radiations by Chemical Methods; Project 39.6, Operation Teapot, ITV-1171, May 1955; Atomic Energy Project, School of Medicine, University of California at Los Angeles; SECRET-RD.

22. Cryden, Joseph, and Gibson, F. P.; Evaluation of Dosimetric Materials; Project 6.1b, Operation Buster, WT-317, March 1952; USASEL and Bureau of Ships; SECRET-RD.

23. Sisk, F. J., and Nielson, D. E.; Evaluation of Military Radiac Equipment; Project 6.1, Operation Snapper, WT-532, January 1953; U. S. Navy, Bureau of Ships and U. S. Army Signal Engineering Laboratories; CONFIDENTIAL.

24. Radiac Training Sets AN/PDR-T1...AN/PDR-39; TM 11-5514, Department of the Army technical manual, dated May 1951, with addendum, dated October 1952. Pages 2, 18, 63, and 64.

25. Wyckoff, H. O., and others;Scientific Director's Report, Annex 1.2, Delayed Gamma-Ray Measurements, Part III - Film Dosimeter Measurements; Operation Greenhouse, WT-81, 1951; Radiation Physics Laboratory, National Bureau of Standards, Washington, D. C.; SECRET-RD.