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# OPERATION SANDSTONE

## NUCLEAR EXPLOSIONS

## 1948





RESTRICTED DATA
ATOMIC ENERGY ACT OF 1946

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# Sandstone

## REPORT 32

SCIENTIFIC DIRECTOR'S REPORT OF ATOMIC WEAPON TESTS
ANNEX II PARTS I, II AND III
THERMAL EFFECTS AND DECONTAMINATION STUDIES

[redacted]

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SCIENTIFIC DIRECTOR'S REPORT

OF ATOMIC WEAPON TESTS

AT ENIWETOK, 1948

Annex 11

# THERMAL EFFECTS AND DECONTAMINATION STUDIES

Part I

## EXPOSURE OF PANELS FOR DECONTAMINATION AND HEAT SENSITIVITY STUDIES

[redacted]

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[redacted]

Task Group 7.6

Project Report

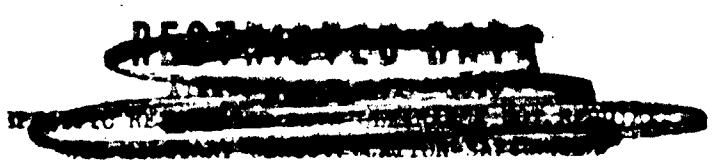
# EXPOSURE OF PANELS FOR DECONTAMINATION AND HEAT SENSITIVITY STUDIES

## OPERATION SANDSTONE

by

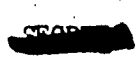
CDR E. J. Hoffman, USN

LT. E. C. Vicars, USN



30 June 1948

Project 7.1-17/RS(BS)-5



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# EXPOSURE OF PANELS FOR DECONTAMINATION AND HEAT SENSITIVITY STUDIES

## I ABSTRACT

Selected metallic and non-metallic surfaces were exposed to the effects of an atomic explosion. A report is made of alpha and beta-gamma contaminati n. Also included are the results of a microscopic and visual examination of the surfaces.

A report of thermal radiation studies of these materials will be forthcoming at a future date.

## II OBJECTIVE

The purpose of this project was to expose sample of various materials to the ex los on of atomic bombs so that these materials could be analyzed for surface effects and the function of distance on these effects. In addition, since a variety of surfaces was subjected to identical contaminating media it is possible to measure the relative resistance to contamination nd the relative ease of decontamination. These tests will provide standards for laboratory developmen- of simulated standards.

## III HISTORICAL

At the CROSSROADS Operation, plans were made to measure the



[redacted]

effect of radiant energy on a variety of substances. Attempts were made to measure the optical spectrum produced during the bomb explosion; however, only very sketchy results were obtained. The thermal radiation effect on the target ships was manifested by a charring of the exposed paint surfaces. Some fires were started but these were generally among test materials loaded aboard the ships, but not in the ship materials themselves. Some of the uncontaminated test panels were forwarded to the Naval Materials Testing Laboratory at the New York Naval Shipyard, where a fairly successful method was evolved for duplicating the effect of radiation with the spectrum emitted by the carbon arc. The complete success of this method will permit laboratory evaluation of the effects of radiation as part of the routine testing of materials.

After Test Baker at Operation CROSSROADS, it was found that all exposed surfaces of the target vessels were heavily radioactive. This was the introduction of the Navy to the phenomena of radioactive contamination following an atomic bomb detonation. This proved to be the most important effect of the bomb when detonated under the conditions of that type of test. The non-target vessels which were present in the Bikini lagoon after the Baker test picked up radioactive materials on all parts of the ship which were exposed to salt water. This forced the Department of the Navy to undertake a large decontamination program without having any previous knowledge of the tolerances, procedures, or processes involved. A long term project for the accomplishment of this program has been established at the Naval Radiological Defense Laboratory at the San Francisco Naval Shipyard.

The program of the laboratory is being directed toward finding the most suitable protective coatings for naval materials afloat and ashore;

these coatings to have a maximum degree of resistance to contamination and to be easily decontaminated. This project is of interest to the Bureaus of Yards and Docks and Aeronautics and to the Corps of Engineers. The first project proposed by the Bureau of Ships for Operation SANDSTONE was designed to assist in decontamination studies. However, under the conditions of the test, no considerable or important contamination was expected. Had there been an unanticipated performance that produced a greater degree of contamination, this project would have proved more valuable. Otherwise, the surface effects of the thermal radiation produced the only significant data.

## IV EXPERIMENTAL

### A. MATERIALS AND EQUIPMENT

Approximately forty organic protective coatings and twenty metallic surfaces on approximately 3 by 5 inch panels were set out at 750, 1000, 1250, 1400, and 1800 yards from the zero point. For Test X-ray two sets were mounted at the 1000 and 1400 yard points. Six sets were placed out for Test Yoke; two at 750 yards, two at 1000 yards, and one each at 1250 and 1800 yards. The materials were applied to the test panels in a manner simulating production methods. The individual samples were mounted by bolting to an angle iron frame erected at 30 degrees to the vertical at each of the above stations. One each of the materials shown in Table I was mounted in each set of panels.

The frame used for mounting the specimens consisted of a steel frame rack made up of 2 x 2 x 1/4 inch angle iron legs with 1 x 1 x 1/4 inch angle iron cross members. The cross members were drilled for screw mounting of the test panels. In order to provide additional support and to allow the specimens to be placed normal to the line to the point of detonation, additional angle

iron supports were bolted to the legs and were adjustable to the desired angle for the rack of 30 degrees to the vertical. The various sections of the assembly were bolted together with 1/2 inch steel bolts and the specimen placques were 2 3/4 x 4 3/4 x 1/8 inch. Except for the metals, all specimens were supported in a 5 x 3 x 1/4 inch mounting plate. The steel mounting plate was secured to the angle iron cross members by 3/16 inch bolts through the four corners of the plate. The frame and layout of specimens are shown in Figure 1.

The angle iron legs and backing-up supports were driven into the coral to a depth of about 18 inches. This permitted a distance of approximately two feet between the ground and the lowest specimens. The specimens were mounted and the frames driven into the coral ten days prior to X-ray and Yoke days. Specimens were recovered on the day following each test.

B. CALIBRATION

Calibration of the surfaces is being accomplished after the test and will consist of duplicating the damage by exposure to a carbon arc suitably timed and filtered to produce effects that are visually and microscopically similar.

V RESULTS AND CONCLUSIONS

The visual inspection and radiological survey given in Enclosure A indicate that the degree of contamination on the samples was small. It is considered that this condition can be attributed to the up-wind locations for the test installations and the fact that they were not in an area where a major fall-out occurred. Subsequent to X-ray and Yoke days, however, when minor fall-out did occur in these areas, slight amounts of contamination were

observed. Contamination present was not in any case above that which can be attributed to handling, slight fall-out or physical retention of particles with induced activity.

The visual inspection of the samples revealed considerable damage caused by blast, heat, flying sand and missiles. It should be noted that combustion of the various samples was evident only in the incipient stages and that those materials which had been expected to suffer heavily from this type of destruction were not so affected. It is possible that the sand blast occurring immediately after the detonation put out fires before the samples were consumed.

The information contained in Enclosure A is considered sufficient to complete the phase of study concerned with the radiological survey and visual inspection. Consequently, an evaluation of the thermal radiation effects has been initiated. In this phase of the study, the individual contributions of the blast effects and heat effects will be examined and the cause of such conditions as the loss of transparency, pitting, charring, etc. will be sought. The results of this study will be reported at a later date.

In the planning for future tests, it will be desirable to continue examinations of the effects of the bomb detonation on various materials. These should be materials for which promise of widespread use is indicated from laboratory findings. In the planning of future tests consideration should be given to an installation of samples on a raft or float so as to eliminate the sand blast effect.

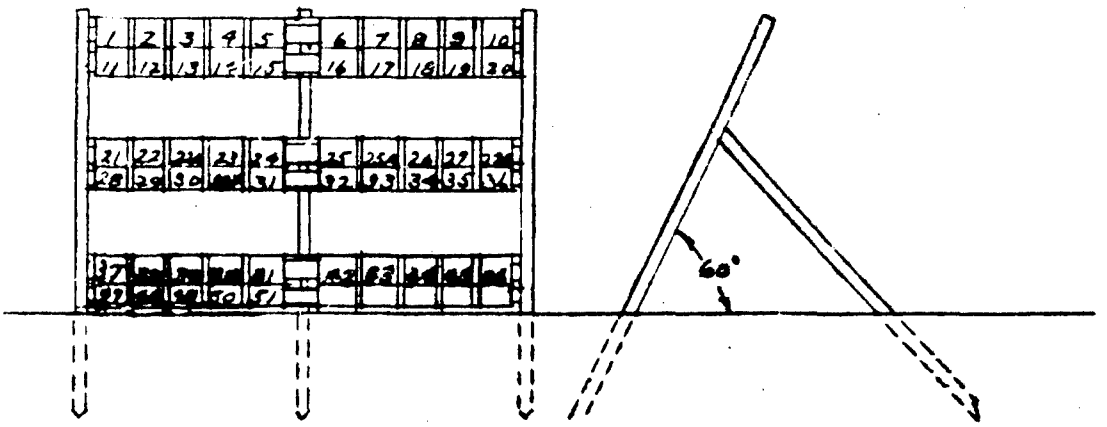
TABLE I

Materials Used in Test Panels and their Location on the Angle Iron Frame as Shown in Figure 1

| Material | Frame Location Number | Material | Frame Location Number |
|---|---|---|---|
| Phenol-formaldehyde | 1 | Asphalt | 20 |
| Urea-formaldehyde | 2 | Paraffin | 21 |
| Aniline-formaldehyde | 3 | Buna-S-Rubber, GR-S | 22 |
| Phenol-furfural | 4 | Natural Rubber, Hevea | 22A |
| Allyl Resins | 5 | Buna-N-Rubber Per Bunan | 23 |
| Alkyd Resins | 6 | Chlorinated Rubber, GR-M Neoprene | 24 |
| Melamine Resins | 7 | Polysulfide Rubber, LP-3 | 25 |
| Acrylic Resins | 8 | Polysulfide Rubber, LP-2A | 25A |
| Vinyl Resins | 9 | Butyl Rubber, GR-I | 26 |
| Styrene Resins | 10 | Ceramics, Barium Oxide | 27 |
| Cellulose Esters | 11 | Ceramics, Low Lead | 27A |
| Cellulose Ethers | 12 | Silicones | 28 |
| Fluorinated Hydrocarbons | 13 | Glass | 29 |
| Casein Resins | 14 | Mica Natural | 30 |
| Furane Resins | 15 | Mica Pasted | 30A |
| Polyethylene Resins | 16 | Aluminum | 31 |
| Polyamide Resins | 17 | Tin | 32 |
| Coumarone-indene Resins | 18 | Cadmium | 33 |
| Polyterpene Hydrocarbons | 19 | Copper | 34 |

TABLE I (Continued)

| Material | Frame Location Number | Material | Frame Location Number |
|---|---|---|---|
| Magnesium | 35 | Inconel | 43 |
| Lead | 36 | Brass | 44 |
| Nickel | 37 | Bronze | 45 |
| Zinc | 38 | Alnico | 46 |
| Chromium | 39 | Duriron | 47 |
| Low Carbon Steel | 40 | Beryllium Copper | 48 |
| Stainless Steel (18-8) | 41 | Beryllium Aluminum | 49 |
| Monel | 42 | Tin-lead Solder (50-50) | 50 |
| | | Lithium Alloys | 51 |




Installation for measurement of radiant heat and degree of contamination for selected materials.

Figure 1

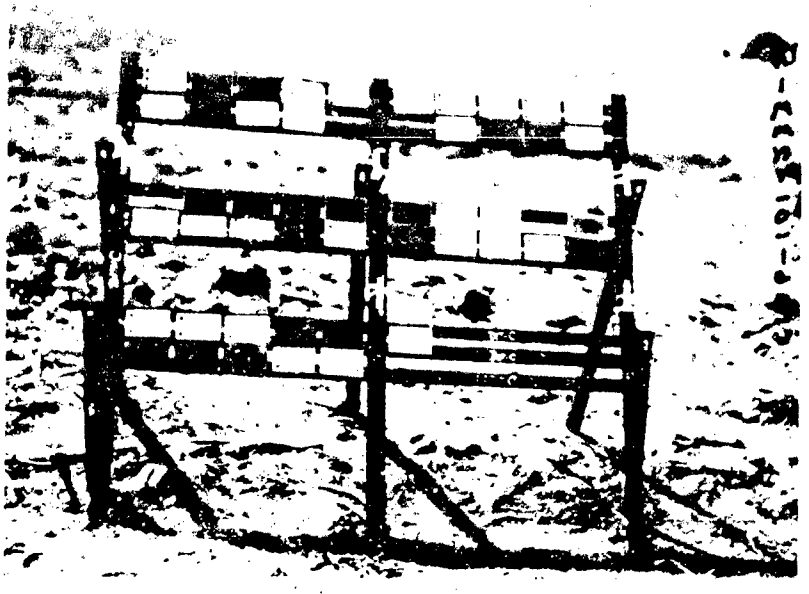


FIGURE 2 (CWP-101-533-2)
arrangement of test samples (before test)

FIGURE 3 (RYS_2869-CM949)
arrangement of test sample (after test)

NOTE - Figures2 and 3 show representative test installations prior and subsequent to a detonation. It should be noted, however, that figures 2 and 3 are not the same installation, so that the individual panels cannot be compared.

ENCLOSURE A

Distribution List

| | |
|---|---|
| BuShips, Code 689 | (3) |
| Comdr. J. J. Fee | (1) |
| Lt. E. C. Vicars | (2) |
| H. F. Matthiesen | (1) |
| C. R. Schwob | (1) |
| W. H. Sullivan | (2) |
| Central Files | (2) |

Abstract

The results of physical observations made by the Assay Group on several series of samples submitted by Lt. Vicars are presented.

Included are measurements of alpha and beta-gamma contamination, and reports of the microscopic and visual examination of approximately two hundred and fifty samples. The information is arranged systematically.

A complete study of the materials is contemplated for a later date.

[redacted]

## INTRODUCTION

Six series of samples of materials of interest to the Navy and the other armed forces were submitted to this laboratory for examination. This preliminary report lists the results of some physical tests and examinations performed. Later this information will be supplemented by the results of a more complete study of some or all of the samples.

Procedure: The large number of samples suggested the use of an "assembly-line" technique. Samples were routed to definite "stations" in the laboratory where the individual tests were performed. These were:

1. Beta-gamma survey. An Eck and Krebs GM tube was used which was mounted in a probe securely clamped at a distance of one-half inch from the sample. The wall thickness of the tube corresponded to approximately 30 mg/cm$^2$ and the area exposed was 2-1/8 by 1-1/4 inches. A Berkeley Scientific Co. Decimal Scaler, Model 100, was used. Each count was preceded by a background count and followed by a standard count to "normalize" the instrument. The standard used was a gamma emitter, Co 60, and its use demonstrated the fact that, at higher counting rates, variations due to the tube and electronic equipment were within 2%.

2. Alpha survey. Two devices were used, a Victoreen Model SIC-2A USSR726 for one half of the sample, and a battery operated DC "Poppy" for the other half. Both instruments appear to have a maximum sensitivity enabling them to detect 5 x 10$^{-6}$ microgram of plutonium per square inch.

3. Microscopic examination. This was conducted with a Bausch and Lomb binocular microscope with a 10X wide focus eyepiece and a 2X objective. The lighting was sharply oblique. The following data were sought:

   a. extent, degree and depth of pitting, searing, scoring, gouging and granulation
   b. the amount and appearance of scale
   c. comparison with a sample of the original material not subjected to exposure
   d. foreign material with conjecture as to its nature (sand, marine growth, salt, carbonaceous material, rust, etc.)



[redacted]

4. Visual examination. Each sample was examined by two independent observers whose observations are combined in tables. The following data were sought.

a. Comparison with untreated sample with respect to color, transparency, etc.
b. Area of charring or scaling; distribution of foreign matter
c. Corrosion and other changes on the back of sample
d. Chipping or fracture; area of pitting
e. Warping, oxidation
f. Miscellaneous effects

The data so obtained are presented in the form of tables:

TABLE I. Tabulation and description of samples received. In some cases, two samples of the same material were found to be packed in one box. In these cases, one of the samples was given its proper number and the other was given the same number primed. For example, if two samples of material number 45 were found in box A, the first was assigned the number 45A, the second 45'A.

Pages 6 & 7

TABLE II. Observations. Listed in order are the beta-gamma count (B-G), the alpha count (A) ("A-zero" indicates background), and the results of the microscopic and visual examinations. The counts reported are net counts per minute (observed count less background). For B-G, the reported value was obtained by averaging the counts from four separated areas of each sample. Alpha counts were measured over the whole area of the sample. Adjectives used in describing the physical state of the sample were chosen according to the definitions in Webster's Intercollegiate Dictionary. Some terms of looser meaning were defined empirically as follows:

| | |
|---|---|
| Slight | Less than 10% |
| Minor | 10-30% |
| Moderate | 30-60% |
| Extensive | 60-85% |
| Excessive or Extreme | 85-100% |

Page 8

[redacted]

NOTE: Samples to which Roman numerals have been assigned were not positively identifiable. They are listed in what is believed to be the proper classification as deduced from comparison with the set of original samples.



[redacted]

TABLE I.

List of Samples

| SAMPLE NO. | MATERIAL |
|---|---|
| 1 | phenol formaldehyde |
| 2 | urea formaldehyde |
| 3 | aniline formaldehyde |
| 5 | allyl resin |
| 7 | melamine resin |
| 8 | acrylic resin (lucite HC 201 H-3) |
| 9 | vinyl resin (Vinylite VS 1310 K-3) |
| 10 | styrene resin (polystyrene J-7, mfgd. by Acadia Synthetic Products) |
| 11 | cellulose ester (Lumarith 11513 L-12) |
| 12 | cellulose ether (Ethocel (ethyl cellulose) M-12) |
| 13 | fluorinated hydrocarbon (Teflon N-6) |
| 14 | casein resin |
| 17 | polyamide resin (Nylon 10001 S-3) |
| 22 | Buna S rubber (GR-S) |
| 22A | natural rubber (Hevea) |
| 23 | Buna N rubber (Per Bunan) |
| 24 | chlorinated rubber (GR-M Neoprene) |
| 25 | polysulfide rubber (LP-3) |
| 25A | polysulfide rubber (LP-2A) |
| 26 | "GR-I" |
| 27 | ceramics, barium oxide |
| 27A | ceramics, low lead |
| 28 | silicone |
| 29 | glass |
| 30 | natural mica (Z-11) |
| 30A | pasted mica (ZZ-9) |
| 31 | aluminum |
| 32 | tin |
| 33 | cadmium |
| 34 | copper |
| 35 | magnesium |
| 36 | lead |
| 37 | nickel |
| 38 | zinc |
| 39 | chromium plated low carbon steel |
| 40 | low carbon steel |

| SAMPLE NO. | MATERIAL |
|---|---|
| 41 | stainless steel (18-8) |
| 42 | monel |
| 43 | inconel |
| 44 | brass |
| 45 | bronze |
| 46 | aluminum-nickel alloy |
| 47 | Duriron |
| 48 | beryllium copper |
| 49 | K Monel |
| 50 | tin-lead solder (50-50) |
| 51 | lithium alloy (11% Li-Mg Alloy) |

[redacted]

TABLE II

OBSERVATIONS

Sample No.

1 A. B-G 21, A-zero; complete loss of transparency; overall pitting; extensive charring; traces of white salt.

1 B. B-G 10, A-zero; opaque at edges; extensive charring; minor pitting; traces of white salt.

1 C. B-G 7, A-zero; complete loss of transparency; extensive pitting and charring; moderate warping; small quantity of white salt.

1 D. B-G 17, A-zero; complete loss of transparency; excessive warping; extensive charring.

1 E. B-G 17, A-zero; transparency partly lost; surface melted, stiff and brittle; extensive charring; slight warping.

1 F. B-G 13, A-zero; transparency retained; one corner charred; moderate pitting; large number of black specks on surface; moderate amount of white salt.

2 A. B-G 4.5, A-zero; original surface changed; pinkish hue; minor rust and scaling; minor deep pitting; trace of white salt.

2 B. B-G 43, A-zero; surface roughened; uneven charring; two deep pits; slight warping; trace of white salt.

2 D. B-G zero; A-zero; stiff; scattered sand; uneven charring; flecks of white salt.

2 E. B-G 5, A-zero; pink color; moderate pitting; slight warping and charring; large number of white salt specks.

2 F. B-G 22, A-zero; smoothness and luster gone; moderate pitting; slight warping; thin layer of surface charred.

2'D. B-G 14, A-zero; surface rough; extensive charring, pitting and melting; condition poor; moderate white salt.

3 A. B-G zero, A-zero; surface rough and charred; white salts and rust on back of mount.

3 B. B-G 5, A-zero; irregular deep pitting and deep charring; small specks white salt.

3 D. B-G zero, A-zero; reddish brown color; surface rough and channeled; excessive pitting; sample broken into two parts.



[redacted]

3 E. B-G 16, A-zero; brown charred channeled surface; slightly warped; condition very poor; trace of white salt; in two pieces.

3 F. B-G 26, A-zero; smoothness and luster gone; complete charring; condition very poor.

III A. B-G 69, A-zero; color dull; extensive and uneven corrosion; moderate pitting and warping; trace of white salt.

5 A. B-G zero, A-zero; surface pitted and warped; specks of white salt; rust on back of mount.

5 B. B-G 3, A-zero; extensive pitting and charring; diminished transparency; one corner fractured; trace of white salt.

5 C. B-G 37, A-zero; extensive pitting; fissure down center of plate; condition poor.

5 D. B-G 24, A-zero; transparency retained in spite of extreme pitting; slight warp; trace of white salt.

5 E. B-G 33, A-zero; very extensive pitting; decreased transparency; moderate warping; condition fair.

5 F. B-G 25, A-zero; no noticeable effect other than minor pitting; good condition; trace of white salt.

7 A. B-G 1, A-zero; tarnished and pitted; carbonaceous material at edges; warped and stiff.

7 B. B-G zero, A-zero; minor pitting; one end charred.

7 C. B-G 6, A-zero; surface charred; extensive pitting; warped; complete loss of flexibility.

7 D. B-G 6, A-zero; complete loss of transparency; moderate charring; extensive pitting; slight warp.

7 E. B-G 14, A-zero; extensive pitting; fracture; slight warp.

7 F. B-G 24, A-zero; no effect other than minor pitting.

8 A. B-G 10, A-zero; transparency partly lost; pitting; moderate charring; warp; extensive deposits of white salt.

8 B. B-G zero, A-zero; transparency decreased by pitting and charring; trace of white salt.

8 D. B-G 23, A-zero; complete loss of transparency; rough surface; moderate charring; trace white salt; fair condition.

8 E. B-G 15, A-zero, transparency decreased; moderate charring and pitting; sample stiff and warped; flecks of white salt.

8 F. B-G 27, A-zero, moderately pitted; condition good.

8'D. B-G 22, A-zero; surface excessively pitted; transparency lost; streaks of dirt on surface; trace of white salt.

VIII A. B-G 67, A-zero; surface pitted, lusterless; extreme rust on back; white salts and carbonaceous material.

9 A. B-G 14, A-zero; transparency lost; extensive pitting, charring and warping; back rusted; speckled with large amount of salt.

9 B. B-G 11, A-zero; transparency lost; extensive pitting and charring; slight warp; entire surface blistered; material melted.

9 C. B-G 65, A-zero; surface charred and blistered; transparency destroyed; sand on surface, condition very poor.

9 D. B-G 22, A-zero; fractured; pieces pitted and warped; transparency lost; trace of salt.

9 E. B-G 35, A-zero; extensive melting and charring causing brazing and channeling; transparency lost; covered with specks of salt.

9 F. B-G 25, A-zero; transparency partly lost by charring and moderate pitting.

IX D. B-G 34, A-zero; chipped, scarred and fractured; brown smudges; trace of white salt; yellow scale; condition poor.

10 A. B-G 10, A-zero; transparency lost; charred; warped; imbedded sand.

10 B. B-G 30, A-zero; decrease in transparency; edges charred; moderate pitting; trace of salt.

10 D. B-G 35, A-zero; all transparency lost; moderate warping; extensive pitting; layer of sand imbedded in surface.

10 E. B-G 26, A-zero; transparency lost; moderate charring and pitting; sample brittle and warped.

10 F. B-G 14, A-zero; moderate pitting.

10'D. B-G zero, A-zero; transparency lost, extensive pitting and deep charring; sample stiff; heavy white salt deposit.

11 A. B-G 4, A-zero; transparency lost; bubbles on surface; moderate warping.

11 B. B-G 2, A-zero; pitted; moderately charred; excessively warped; blistered.

11 C. B-G 23, A-zero; transparency lost; blistered; warped; heavy salt deposit.

11 D. B-G 8, A-zero; extensive pitting; transparency lost; blistered.

11 E. B-G 42, A-zero; transparency partly lost; pitting; blistered; covered with specks of salt and sand.

11 F. B-G 11, A-zero; moderate pitting; condition fair.

12 A. B-G zero, A-zero; extensive pitting and charring; extensive deposits of salt and sand; complete physical change.

12 B. B-G zero, A-zero; pitted; surface covered with sand.

12 C. B-G 31, A-zero; fused and charred; pitted; poor condition.

12 E. B-G 38, A-zero; fused; deep pitting; large salt particles; condition poor.

12 F. B-G 41, A-zero; charred; fused, covered with salt and sand.

13 A. B-G 10, A-zero; extensively pitted; slight warp; luster and smoothness lost; minor black scale.

13 B. B-G 7, A-zero; moderately pitted; charred; warped.

13 C. B-G zero, A-zero; lost of finish; extensive pitting and charring; warped.

13 D. B-G 27, A-zero; extensive pitting and charring; warped.

13 E. B-G 12, A-zero; extensive pitting and charring; warped.

13 F. B-G 36, A-zero; surface discolored; moderate pitting, warping and charring; thin layer of carbonaceous material.

14 A. B-G 13, A-zero; discolored; moderate pitting, warping and charring; brittle; salt flakes.

14 B. B-G 4, A-zero; coarse and grainy; warped; brittle; small blister; thin layer of carbonaceous material.

14 C. B-G 78, A-zero; rough brown surface; expanded; moderate pitting, warping and charring; condition very poor.

14 E. B-G 22, A-zero; yellow-brown color, rough surface; shallow pits; warping and charring.

14 F. B-G 27, A-zero; black color; slight pitting; moderate warp; brittle.

17 A. B-G 9, A-zero; gray color; white scales; excessive pitting; small blisters; partially fused.

17 B. B-G 4, A-zero; coarse texture; dull color; moderate shallow pitting; edges warped; carbon and salt particles present.

17 C. B-G 53, A-zero; dull gray color; black scale; extensively pitted; deformed; covered with large white crystals.

17 D. B-G 64, A-zero; excessively pitted and charred; moderate warp; heavy carbon scale; some white salt.

17 E. B-G 48, A-zero; rough surface; dull color; moderate shallow pitting; deformed; white and black specks.

17 F. B-G 29, A-zero; gloss retained; moderate pitting and warping; salt specks; condition fair.

22 A. B-G 46, A-zero; elasticity retained; some pitting; white salt deposits.

22 B. B-G zero, A-zero; coarse surface; charred; deformed; white salt; elasticity retained.

22 D. B-G 5, A-zero; rough; charred and deformed; pitted; white-brown occlusions.

22 E. B-G 50, A 7; rough; charred; shallow pits; brown and white specks.

22 F. B-G 24, A-zero; granular surface; charred; slightly warped; shallow pits; moderate foreign matter.

22(A)A. B-G 3, A-zero; rough; charred and warped; fine pits; white salt.

22(A)B. B-G 16, A-zero; very rough; fused; heavy deposit white salt.

22(A)C. B-G 40, A-zero; surface fused; pitting and charring; sand in surface.

22(A)D. B-G 31, A-zero; rough; charred; crystals, sand, salt attached.

22(A)E. B-G 31, A-zero; rough charred; fused; black scale.

22(A)F. B-G 42, A-zero; rough; moderate pitting; salt specks.

23 B. B-G zero, A-zero; rough; charred; some salt.

23 D. B-G 18, A-zero; charred; elasticity retained.

23 E. B-G 19, A-zero; charred; elasticity retained; warped; shallow pits; white specks.

23 F. B-G 24, A-zero; charred; slight warping; carbonaceous scale.

23'D. B-G 5, A-zero; rough; slight warp; heavy black scale; overall white salt deposit.

24 A. B-G zero, A-zero; gray color; overall pitting; extensive charring and warping; small salt specks.

24 B. B-G 5, A-zero; dull color; granular; charred; warped.

24 C. B-G 17, A-zero, very rough; luster lost; extensive charring; slight warp; salt specks.

24 E. B-G 26, A-zero; rough, charred; slight warp; fine salt and dust specks.

24 F. B-G 30, A-zero, rough; minor charring; wide shallow pits; slight warp.

25 D. B-G 23, A-zero; rough; extensive pitting and scarring; extensive warp; sand and salt.

25 E. B-G 12, A-zero; rough; charred; warped; sand.

25 F. B-G 31, A-zero; rough; slight scarring; warp; white salt.

25'D. B-G 11, A-zero; rough; minor charring and warping; heavy residue of white salt.

25(A)A. B-G zero, A-zero; surface ruptured in spots; very rough; slight pitting; salts present; elasticity retained.

25(A)B. B-G 3.0, A-zero; rough; slight carbonaceous film; warped; fibers project from face.

25(A)D. B-G 36, A-zero; torn; overall pitting; granular; black scaly char; moderate warp.

25(A)E. B-G 43, A-zero; rough; slight salt deposit; charred; slight warp; elasticity retained.

25(A)F. B-G 32, A-zero; charred; moderate pitting; fused; scale, salt and sand present.

25'(A)D. B-G 38, A-zero; rough; charred; slight warp; minor deep pits; elasticity retained.

26 A. B-G 22, A-zero; rough; discolored; slight warp; white salt specks imbedded in surface.

26 B. B-G 19, A-zero; dull surface; fused; large amount foreign matter.

26 C. B-G 33, A-zero; rough; fused; charred; pitted; salt and carbon.

26 D. B-G 25, A-zero; rough; extreme charring; pitted; white and brown specks.

26 E. B-G 19, A-zero; charred; fused; moderate pitting.

27 B. B-G 18, A-zero; rough; discolored; minor pitting; moderate charring.

27 C. B-G 167, A-zero; rough; chipped; pitted; small blisters.

27 D. B-G 138, A-zero; gray color; moderate large pits; transverse fissures; chipped; small blister; specks of salt.

27 E. B-G 41, A-zero; dull color; chipped; extreme pitting; brown specks.

27 F. B-G 21, A-zero; slight blisters and pits; black and white deposits.

27(A)B. B-G 1, A-zero; luster dulled; moderate pitting; scarring and chipping.

27(A)C. B-G 12, A-zero; gray color; rough surface; extensive pitting; small blisters; chipped; fissured; specks of foreign matter.

27(A)D. B-G 138, A 7; pitted; blisters clustered around pits; chipped; spots of green salts.

27(A)E. B-G 59, A-zero; luster lost; extensive deep pits; edges charred; flecks of white and black particles.

27(A)F. B-G 19, A-zero; dull; moderate pitting and blisters; some carbonaceous deposit.

28 A. B-G 15, A-zero; discolored; fused; coarse; minor charring and pitting; slight warp.

28 B. B-G zero, A-zero; discolored; rough; warped; white salt and carbonaceous deposit.

28 D. B-G 17, A-zero; rough; gray; extensive pitting; pebbles and carbonaceous material.

28 E. B-G 42, A7; luster lost; charred; moderate fine pitting; cracks; warped.

28 F. B-G 19, A-zero; gray; slight pitting; slight warp; patches of black scale.

29 A. B-G 41, A-zero; slight etch; white salt; some small pits.

29 B. B-G 18, A-zero; slight etch and stain; white specks.

29 C. B-G 23, A-zero; minor scratches; thin film carbonaceous material; some white specks.

29 D. B-G 12, A-zero; few scratches; moderate white salt; excellent condition.

29 E. B-G 4, A-zero; slight pitting; white and yellow salt.

29 F. B-G 7, A-zero; slightly chipped; black and white specks.

30 A. B-G 25, A-zero; extensively shattered; flaky and cloudy; brown and white specks.

30 B. B-G 50, A-zero; part of mica gone; small scratches; white salt.

30 D. B-G 64, A-zero; extensive scale; moderate loss of material; long fissures.

30 E. B-G 58, A-zero; moderate loss of material; white and black specks.

30 F. B-G 64, A-zero; minor separation of laminations.

30(A)A. B-G zero, A-zero; shattered; partial loss of sample.

30(A)B. B-G zero, A-zero; extensive destruction of surface; one corner charred; opaque.

30(A)C. B-G 69, A-zero; moderate destruction of lamina; moderate charring; heavy deposit of white salt.

30(A)D. B-G 34, A-zero; three-fourths of sample missing; heavily flaked; moderate amount of carbonaceous matter.

30(A)E. B-G 18, A-zero; half of sample missing; moderately flaked; discolored; slight salt deposit.

30(A)F. B-G 68, A-zero; laminations torn and separated; charred in one corner; covered by white salt.

31 A. B-G 1, A-zero; moderate scale; pitted; coarsened crystal structure; extensive coverage by white salt; backing plate rusted.

31 B. B-G 39, A-zero; extensive deep pitting; extensive coverage by white salt; spots of fused brown material.

31 C. B-G zero, A-zero; extensive pitting; plate warped and rusted on edges; extensive coverage by white salt.

31 D. B-G zero; A-zero; evenly pitted; overall white salt specks.

31 E. B-G 18, A-zero; extensive pitting and scaling; extensive coverage by white salt.

31 F. B-G 24, A-zero; moderate pitting and corrosion; slight amount of white salt deposited.

32 A. B-G 39, A-zero; deeply scarred and pitted; corners bent; specks of white salt.

32 B. B-G 3, A-zero; moderate pitting, center extensively corroded.

32 C. B-G 30, A-zero; extensive warping and deep pitting; fissures.

32 D. B-G 28, A-zero; extensive pitting; warped.

32 E. B-G 65, A-15; moderate pitting: thick yellow-white scale; white salt specks.

32 F. B-G 10, A-15; shallow pitting; one edge blackened.

33 A. B-G 12, A-zero; extensive pitting and scarring; gray scales; white salt specks; rusted backing plate.

33 B. B-G 42, A-zero; deeply pitted; gray-black scales; slight deposits of white salt; backing plate pitted and corroded.

33 C. B-G 21, A-zero; extensive pitting; gray-black scales; slight deposit of white salts.

33 D. B-G 31, A-zero; extensive pitting and corrosion; slight deposit of white salt.

33 E. B-G 34, A-zero; extensive pitting and scarring; thin gray scales; extensive coverage by white salt; backing plat rusted.

33 F. B-G 19, A-zero; moderate pitting; blackened surface; whit salt specks.

34 A. B-G zero; A-zero; extensive pitting and corrosion; pink color; copper salts present; back extensively corroded.

34 B. B-G 15, A-zero; minor pitting; purple color; extensive coverage by green-white salts; back extensively corroded.

34 C. B-G 12, A-zero; extensive pitting and corrosion; black spots with specks of green-white salts; warped; back extensively corroded.

34 D. B-G 8, A-zero; extreme roughening; moderate pitting; purple color; copper salts uniformly distributed; red and black scales; back extensively corroded.

34 E. B-G 3, A-zero; extensive pitting and roughening; purple color; red scales; moderate coverage by green-white salts.

34-F. B-G 22, A-15; minor pitting and roughening; purple color; moderate coverage by copper salts; back excessively scratched.

35 A. B-G 11, A-zero; extensive pitting; specks of white salt.

35 B. B-G 60, A-zero; minor pitting and corrosion; extensive coverage by white salts.

35 C. B-G 6, A-zero; extensive deep pitting; slightly warped; slight white salt deposits; back moderately pitted.

35 D. B-G zero; A-zero; moderately pitted; extensive coverage by white salt.

35 E. B-G 25, A-zero; moderately pitted; slight deposits of white salts and black specks.

35 F. B-G 33, A-zero; extensive roughening; minor deposits of granular scales and white salts.

36 A. B-G 10, A-zero; extensive pitting and roughening; warped; slight white salt deposits; minor corrosion of back.

36 B. B-G 12, A-zero; extensive deep pitting; gray-black color; extensively warped; slight deposits of white salts; back moderately corroded.

36 C. B-G 4, A-zero; extensive pitting and corrosion; brittle; extensively warped; minor deposits of white salts.

36 D. B-G 14, A-zero; extensively pitted and warped; both sides moderately corroded; minor white salt deposits.

36 E. B-G 24, A-zero; moderately pitted and scratched; thin black scale; slight white salt deposit; back moderately corroded.

36 F. B-G 39, A-zero; extensively pitted and scratched; gray-black color; slight white salt deposits; back moderately corroded.

37 A. B-G 13, A-zero; dull gray; moderately pitted and scarred; trace of white salt.

37 B. B-G 20, A-zero; luster partially returned; slightly pitted and rusted; traces of green salts.

37 C. B-G 65, A-zero; dull gray; moderately pitted; dust, salt specks and a layer of carbonaceous material on surface; back rusted.

37 D. B-G 51, A-zero; dull gray; moderate pitting; crust of white salts; back rusted.

37 E. B-G 28, A-zero; dull gray; extreme pitting; moderate deposits of green and white salts; half of back corroded.

37 F. B-G 2, A-zero; slightly discolored; minute pits; specks of white salt.

38 A. B-G 23, A-zero; excessive pitting; gray-white scales; slight amount of white salts and rust-colored particles.

38 B. B-G zero, A-zero; moderate pitting; several deeply gouged areas; minor blackening; moderate amount of thick red-brown scales; extensive coverage by white salt.

38 C. B-G 87, A-7; moderately pitted; granular; slight deposits of white salts and organic matter.

38 D. B-G 12, A-zero; moderately pitted; slight white salt deposits.

38 E. B-G 20, A-zero; moderately pitted; slight deposits of black specks and white salts.

38 F. B-G 32, A-zero; moderately pitted; moderate coverage by thick white scales; slight deposit of black and white specks.

39 A. B-G 6, A-zero; gray color; plating ruptured in spots; extensive scoring; specks of white salt and fused brown particles.

39 B. B-G zero; A-zero; slightly dulled and pitted; white and brown scales; rust on edges.

39 C. B-G 5, A-zero; slight pitting; minor coverage by rust and white salts.

39 D. B-G 35, A-zero; moderate pitting and roughening; specks of rust and white salts.

39 E. B-G 20, A-zero; moderate pitting; moderate coverage by rust, fused salt, and brown particles.

39 F. B-G 32, A-zero; slight pitting; moderate coverage by rust, and black particles.

40 A. B-G 42, A-zero; extreme corrosion; specks of white salt.

40 B. B-G zero, A-zero; extreme corrosion and pitting; specks of white salt.

40 C. B-G 68, A-zero; extreme corrosion; extensive coverage by white salt.

40 D. B-G 27, A-zero; extreme corrosion; moderate coverage by scale and white salt.

40 E. B-G 20, A-zero; extreme corrosion; moderate coverage by scale and white salt.

40 F. B-G 46, A-zero; extreme corrosion; moderate coverage by white salt.

41 A. B-G 15, A-zero; dull; minor oxidation; extensive pitting; flecks of white salt.

41 B. B-G 9, A-zero; luster lost; slight rust; minor overall pitting; white and brown specks.

41 C. B-G 6, A-zero; minor pitting and scoring; extensive white salt deposits.

41 D. B-G 24, A-zero; minor corrosion and pitting; white and brown specks.

41 E. B-G 1, A-zero; moderate corrosion and pitting; moderate deposits of white and brown salts.

41 F. B-G 18, A-zero; moderate corrosion; dark stain in center; shallow scoring; white salt deposits.

42 A. B-G 39, A-zero; dulled; rusted; extensive small pits; trace greenish white salts.

42 B. B-G zero; A-zero; dulled; moderate rusting; extensive small pits; trace small green specks.

42 C. B-G 64, A-zero; slightly roughened; extensive pitting; trace of white salt.

42 D. B-G 37, A-zero; roughened; half rusted; extensive pitting; trace of white salt.

42 E. B-G 15, A-zero; dulled and darkened; 2/3 rusted; moderate shallow pitting; minor deposits white and green salt.

42 F. B-G 6, A-zero; dulled; patchy gray scale; minor pitting; moderate deposits of white salts.

43 A. B-G 3, A-zero; luster gone; extensive pitting; white salts; brown globules.

43 B. B-G zero, A-zero; slightly stained; minor shallow pitting; trace of white salt.

43 C. B-G 76, A-zero; dulled; moderate pitting; specks of white salt.

43 D. B-G 70, A-zero; excessively rough; dark brown coating; moderate pitting; trace of white salt and of carbonaceous material.

43 E. B-G 10, A-zero; rough, moderate rusting; extensive pitting; moderate white salt deposits.

43 F. B-G 21, A-zero; dulled; stained; slightly pitted; spotty deposits of white salt.

44 A. B-G 19, A-zero; dull brown color; coarse grainy appearance; moderate pitting; trace of white salt.

44 C. B-G 62, A-zero; dull brown; rough moderately rusted and scaled; moderate pitting; extensive deposit of slivery material and white salt.

44 D. B-G 40, A-zero; dull brown; rough surface; moderate pitting; extensive deposit of slivery gray scales and white specks.

44 E. B-G 112, A 15; rough surface; red discoloration; slight pitting.

44 F. B-G 5, A-zero; dull brown; slightly roughened; minor thin gray scale; moderately scratched; trace white salt.

44'A. B-G 7, A-zero; extensive pitting and chipping; slight melting; trace of white and black specks.

45 A. B-G 5, A-zero; purple tinge; slight pitting; green and white flecks.

45 B. B-G 1, A-zero; red-purple color; rough; corroded; pitted.

45 C. B-G 11, A-zero; purple; rough; thin red scale; minor channeling; green-white specks.

45 D. B-G 2, A-zero; red-violet crust; minor pitting; green-white specks.

45 E. B-G 10, A-zero; purple; patches of red scale; green and white salt deposits.

45 F. B-G 4, A-zero; purple hue; spotty red-brown scale; moderate green-white salt.

46 A. B-G zero, A-zero; moderate pitting; discontinuous scale; heavy white salt deposits.

46 B. B-G 12, A-zero; coarse; corrosion stains; pitted; deeply scored; white salt specks.

46 C. B-G 16, A-zero; pitted; fractured; scarred; large white salt deposits.

46 D. B-G 14, A-zero; moderate corrosion and pitting; fissured; gray scale; white salt specks.

46 E. B-G zero, A-zero; moderate pitting and gouging; white salt specks.

46 F. B-G 20, A-zero; moderate pitting; slight corrosion; one corner black; heavy white salt deposit.

47 A. B-G 5, A-zero; rough; extensive scale and rust; fractured; back corroded; white salt specks.

47 B. B-G zero; A-zero; surface completely altered; chipped; fractured; scale and flakes; white salt specks.

47 C. B-G 30, A-zero; thickly coated with rust; fractured; extensive pitting.

47 D. B-G 4, A-zero; caked with rust; fractured; moderate pitting.

47 E. B -G 31, A 15; thick red-brown scale; very brittle; moderate white salt.

47 F. B-G 16, A-zero; caked with rust; fractured; moderate white salt.

48 A. B-G 1, A-zero; purple hue; blue salt specks; extensive pitting; slight scoring; gray scale.

48 B. B-G 2, A-zero; luster lost; coarse;slight pitting and deep gouging; white salt specks.

48 C. B-G 35, A-zero; extensive deep pitting; extensive white salt deposits, fractured; moderately warped and scarred.

48 D. B-G zero, A-zero; moderate pitting with one large cavity; fractured, with heaviest white deposit at fractures; thin gray scale.

48 E. B-G 24, A-zero; corroded; moderate pitting and gouging; white salt specks.

48 F. B-G 46, A-zero; moderate pitting; slight corrosion; one corner black; moderate gouging and scarring; heavy white salt deposit.

49 A. B-G 24, A-zero; dull; minor scale on front, moderate rust on back; moderate pitting; crystalline undersurface; white salt specks.

49 B. B-G 11, A-zero; minor rust and pitting; thin gray scale.

49 C. B-G 62, A-zero, moderate corrosion; brown scale; carbonaceous matter and salt.

49 D. B-G 68, A-zero; excessive rusting; black scale; numerous salt specks.

49 E. B-G 6, A-zero; excessive rusting; thin black scale; green and white specks.

49 F. B-G 27, A-zero; moderately roughened and corroded; fine pits; black-brown scale; white salt deposits.

50 A. B-G 15, A 15; slight corrosion; extensive pitting; edges bent.

50 B. B-G 15, A 18; dull gray; moderate pitting and corrosion; white salt deposits.

50 C. B-G 33, A 9; dull gray; rough; moderate corrosion; extensive pitting; slight warp; slight carbonaceous scale.

50 D. B-G 33, A 9; corroded; pitted; rough; warped; chipped; minor salt deposits.

50 E. B-G 24, A 15; dull gray; one-half face corroded; moderate pitting and gouging; rough; thin gray scale; heavy salt deposits.

50 F. B-G 25, A 30; dull gray; slight corrosion; extensive pitting; salt deposits in pits.

51 B. B-G 19, A-zero; rough; minor pitting; gray granular surface; corroded on back.

51 C. B-G 30, A-zero; extensive pitting on front and back; corrosion; slight warp; black and white scale.

51 D. B-G 20, A-zero; excessive corrosion and warping; moderate pitting; white and gray scale.

51 E. B-G 54, A-zero; gray; rough; moderate pitting; black scale; back corroded.

51 F. B-G 25, A-zero; gray; minor pitting; white salt specks; back corroded.

51'B. B-G 11, A-zero; gray; rough; minor pitting; gray-brown scale; white salt.

SCIENTIFIC DIRECTOR'S REPORT

OF ATOMIC WEAPON TESTS

AT ENIWETOK, 1948

Annex 11

# THERMAL EFFECTS AND DECONTAMINATION STUDIES

Part II

## THERMAL RADIATION PAPERS

Task Group 7.6

Project Report

# THERMAL RADIATION PAPERS

# OPERATION SANDSTONE

by

Herbert Scoville, Jr., Project Officer

CDR Rudolph M. Langer, USNR

30 June 1948

Project 7.1-17/RS-10

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# THERMAL RADIATION PAPERS

## I ABSTRACT

Thermal radiation papers which had been supplied by the British Ministry of Supply were exposed at various distances in Tests X-ray, Yoke, and Zebra. With one exception all samples were completely burned in Test X-ray, and this one sample at about 3500 yards corresponded to radiation conditions producing pain on the exposed skin of human beings. In Test Yoke, a wider range of exposures was obtained and these indicated similar effects at approximately 1000 yards greater distance from the point of detonation. Comparison of the energy released in Tests X-ray and Yoke indicated that the total thermal energy was approximately twice as great in Test Yoke as in Test X-ray.

## II OBJECTIVE

The purpose of this project was to measure the thermal radiation density as a function of distance from the point of detonation. Since the response of these papers has been correlated with human exposures, the results should be useful for measuring physiological effectiveness of this type of radiation following an atomic bomb explosion. Furthermore, these papers offer a method of calculating the fraction of the energy of the bomb which is released as thermal energy.

## III HISTORICAL

Papers similar to those which were exposed in Operation SANDSTONE

were used during Operation CROSSROADS with considerable success by Dr. William Penny, Operational Research Group, British Ministry of Supply. Calculations based on data from the papers gave reasonable values for the thermal energy at the source. The complete results of the Bikini tests with calibration data are given elsewhere (1)*.

Because of the importance of the thermal radiation effect in analyzing the medical aspects of atomic bomb detonations, the Armed Forces Special Weapons Project initiated the current project with the thermal radiation papers. When approval was received, samples of the papers were requested from Dr. Penny, who agreed to cooperate by supplying the paper and carrying out new calibrations.

## IV EXPERIMENTAL

### A. MATERIALS

Two-inch square samples of "Green" paper were fixed to plywood squares with scotch tape and placed normal to a line to the point of detonation on stakes. A small sample of the paper is enclosed in Figure 1. The squares were located for Test X-ray at 100-yard intervals beginning at 500 yards and extending, where practicable, out to 4000 yards. In addition, samples were placed at intermediate locations on structures erected for other purposes. In particular samples were placed where the heat and light were being measured by other means (2). Since all the closer samples were completely burned during Test X-ray, more distant stations were used in Test Yoke. Unfortunately geographic difficulties

* Numbers in parentheses indicate references on page 7 of this report.

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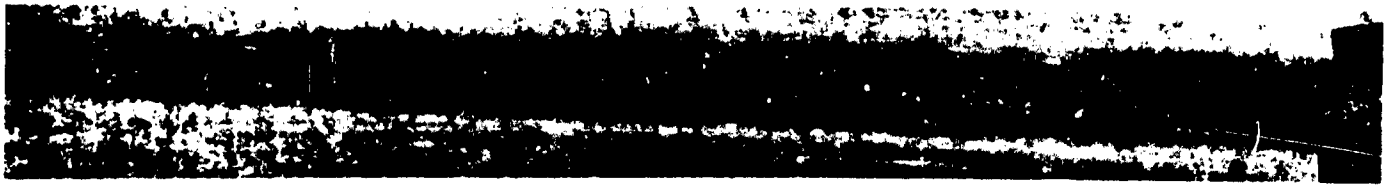

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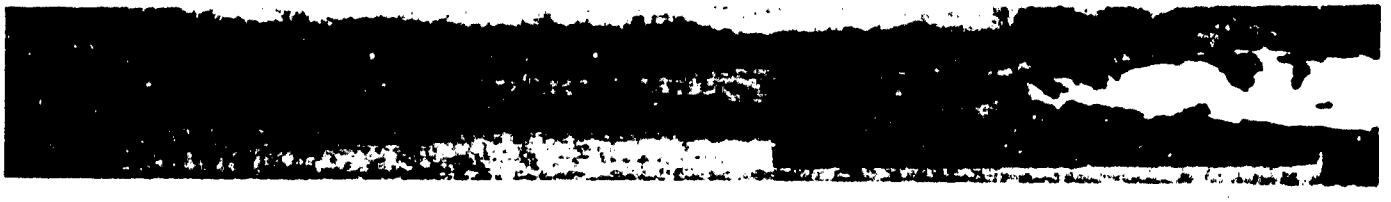

1 Sec.

Figure 1

Calibration of "green" heat sensitive paper with a wood background with light from a 1000 watt tungsten searchlight ($\sim$ 3000°K). The energy is obtained at any point from the equation $\mathcal{E} = 9 \times$ time in cal/cm$^2$. The exposure interpolation is linear.



[redacted]

prevented placement of samples at the proper distances during Test Zebra. In Test Yoke a 3/4 inch hole was drilled in the plywood to study the importance of air backing.

B. CALIBRATION

A calibration of the papers used in these tests will be made by Dr. Penny and forwarded as soon as available. Since the sensitivity of the papers is a function of the length of time over which the exposure is given, they will be calibrated for 1 and 3 second exposure times. Additional studies on these papers have also been initiated at the Material Laboratory, New York Naval Shipyard, Brooklyn, New York, where radiation simulating that of the bomb in spectral distribution and duration at near and far distances will be used. Exposures of 0.3 and 1 to 3 seconds were used in the calibrations already completed at this laboratory, and these were used for the results given in this report. Copies of such calibration strips are shown in Figure 1.

C. OPERATIONS

The plywood squares containing the heat sensitive papers were placed in position on stakes at the distant locations two days prior to the explosion and at the closer locations on minus one day. This was necessitated by the inability to visit the distant islands just prior to the test. Unfortunately there were frequent showers in the area, and it was observed that the heat sensitive paper changed to a greenish color when subjected to moisture. The effect of this on the calibration is not known, but attempts are being made to check this feature. The paper samples

were recovered on plus one day and plus two days again with the object of keeping the period of exposure to the elements to a minimum.

## V RESULTS

The results of the exposure of the heat sensitive papers to the radiation from the bomb are summarized for Test X-ray and Yoke in Table I. Only one sample was collected following Test X-ray since the papers at all of the closer stations were completely burned, and no stations at more distant locations were available. In Test Yoke samples were recovered which ranged all the way from no effect to complete burning. The papers exposed in the Test Yoke showed evidence of having been affected by moisture, and the effect of this on calibration has not as yet been determined. The air backing in the central section of the paper had no visible effect on the heat sensitivity. No distant stations were available for the exposure of the paper in Test Zebra, and all papers at distances closer than 3000 yards, were completely burned.

## VI DISCUSSION

In the report on the results obtained on these papers at Bikini (see reference page 2), the results of the comparison produced on this paper with the effects on human subjects are outlined. These comparisons may be summarized as follows:

a. "A visible change of color on the painted paper corresponding to radiation conditions producing marked discomfort to a normally clothed man".

## TABLE I

### Thermal Radiation Papers (Penny)

| No. | Test | Location | Distance | Q(cal/cm²) 0.3 sec Exposure | Q(cal/cm²) Long Exposure | $E_t$ (tons of TNT) 0.3 sec Exposure | $E_t$ (tons of TNT) Long Exposure |
|---|---|---|---|---|---|---|---|
| 29 | X-ray | Kirinian # 2 | 3450 yds | 4 | 5 (2 sec) | 4800 | 6000 |
| | | All closer samples were completely burned. | | | | | |
| 51 | Yoke | Bokonaarappu #1 | 5770 yds | 0 | 0 | | |
| 52 | Yoke | Bokonaarappu #1 | 5770 yds | 0 | 0 | | |
| 53 | Yoke | Bokonaarappu #2 | 5300 yds | 1 | 1.5 (1 sec) | 2850 | 4200 |
| 54 | Yoke | Bokonaarappu #2 | 5300 yds | 1 | 1.5 (1 sec) | 2850 | 4200 |
| 105 | Yoke | Bokonaarappu #2 | 5300 yds | 1.2 | 1.7 (1 sec) | 3350 | 4800 |
| 57 | Yoke | Yeiri #4 | 4000 yds | 6* | | 9700 | |
| 58 | Yoke | Yeiri #4 | 4000 yds | 6* | | 9700 | |
| 60 | Yoke | Aitsu #5 | 3500 yds | 8 | | 10,000 | |
| 61 | Yoke | Aitsu #5 | 3500 yds | 7.5 | | 9400 | |
| 102 | Yoke | Aitsu #5 | 3500 yds | > 8 | | > 10,000 | |
| 104 | Yoke | Aitsu #5 | 3500 yds | 8 | | 9400 | |
| 106** | Yoke | Aitsu #5 | 3500 yds | | 5 (3 sec) | | 6200 |
| 62 | Yoke | Aitsu #6 | 2900 yds | > 8 (completely burned) | | > 7000 | |
| 63 | Yoke | Aitsu #6 | 2900 yds | > 8 (completely burned) | | > 7000 | |

* These samples may have been slightly shielded by trees on the island.

** This was a sample of paper remaining from Operation CROSSROADS.

[redacted]

b. "A full red color change corresponding approximately to radiation conditions producing pain on the exposed skin. More severe conditions were not investigated with human subjects."

On the basis of these comparisons it is possible to estimate that condition (b) would have existed following Test X-ray at a distance of about 3500 yards from the point of detonation. In Test Yoke this same condition might have extended out another thousand yards. Condition (a) would have existed at Test Yoke at a distance of 5300 yards. These values are admittedly rough, but they may provide some estimate of the extent of thermal radiation on human beings following the bomb detonation.

On the basis of measurements made by these papers it is possible to make a very rough estimate of the total thermal energy released by the explosion of the bomb. This may be accomplished by means of the following equation.

$$E_t = 4\pi QR^2/1.02 \times 10^9$$

where $E_t$ = the thermal energy expressed as tons of TNT

$Q$ = the radiation density in cal/cm$^2$ and

$R$ = the distance in centimeters

The values of E obtained for the papers exposed in Tests X-ray and Yoke are included in the final column of Table I. The data are insufficient and are too variable to draw any final conclusions, but as an approximation it might be said that from these results the thermal energy from Test X-ray was approximately 5000 tons of TNT equivalent as compared with 9000 tons in Test Yoke. Measurements made by Dr. Penny for Test Able



[redacted]

at Bikini gave values of about 2000 tons. Further analysis of these data would not appear warranted.

## VII CONCLUSIONS AND RECOMMENDATIONS

On the basis of the exposure of the thermal radiation papers it is estimated that the thermal radiation would have produced effects on human beings at distances less than 3500 yards in Test X-ray and 4500 yards in Test Yoke. The total thermal energy released in Test X-ray was about one-half that released in Test Yoke.

The thermal radiation papers exposed in the open as they were in the SANDSTONE test are not satisfactory devices for measuring the thermal radiation. The effect of moisture on these papers makes them unsuitable for field work unless adequate protection can be provided. If precise measurements are required in the future, it is recommended that more elaborate constructions be used for the exposure of these papers.

## VIII REFERENCES

(1) "High Temperature Radiation and Heat Sensitive Papers," Operational Research Group Report 354 dated 11 July 1947.

(2) See Projects 7.1-17/RS(BS)-5 and 7.1-17/RS(BM)-13.



[redacted]

# SCIENTIFIC DIRECTOR'S REPORT

# OF ATOMIC WEAPON TESTS

# AT ENIWETOK, 1948

## Annex 11

## THERMAL EFFECTS AND DECONTAMINATION STUDIES

## Part III

## THERMAL RADIATION PLAQUES

Task Group 7.6 - Project Report

# THERMAL RADIATION PLAQUES

# OPERATION SANDSTONE

by

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*This is an abstract prepared by the staff of the Scientific Director of a preliminary report by these authors. When a final report is received it will be reproduced as Part III, Section 2 of this annex.

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ABSTRACT

This is a preliminary report on the work, since the analysis of available data is not complete. A preliminary value of 4000 tons TNT equivalent for the average of X-ray and Yoke total energy radiated was obtained. This number may be in error by 50%. The effective diameter of the ball of fire was about 200 yards. Most thermal effects take place within two seconds of the detonation. There is a probability that the infra-red predominates. The total energy seems to decrease with distance according to the law

$$E = E_0 e^{-0.9R}.$$

## MATERIALS

Materials were selected because their optical, thermal, and mechanical properties would permit conclusions to be drawn regarding the temperatures or exposures attained and because of their importance in the construction of buildings or military equipment. The classes of materials selected were metals, textiles, wax, wood, plastics, paint, paper, glass and rubber.

### Metals

Aluminum sheets from 0.00035 to 0.125 inches in thickness, copper in 0.010 inch matt sheet, brass in 1/8 inch strip, lead in thin foil and thick block, steel, stainless and 1/16 inch cold-rolled, tin sheet, 0.01 inch thick, and chromium plate on 0.01 inch corrosion resistant steel, were used. These metals were exposed bare as well as painted; and with and without glass and plastic filters. The melting of the metal specimen or the discoloration of a paint put on as an absorber or indicator was observed. The advantage of metallic foil as a sensitive receiver is the low heat capacity and relatively high mechanical strength. The disadvantage of low emissivity is overcome by paint or India ink.

Wood

Douglas fir, balsam, and Phillipine mahogany were exposed both painted and bare. Plywood was used as a carrier for several kinds of paint and stain. The threshold sensitivity for discoloration of bare pine wood is about 2 cal per $cm^2$. With lacquer the sensitivity is smaller; with dark stain a greater sensitivity is obtained. For low degrees of charring the texture, color and depth of penetration are of interest and variations due to grain are helpful rather than troublesome.

Paper

Smooth, blotter, kraft and tissue paper, white, black, green and blue were available. Specially calibrated radiation receiver papers from the National Bureau of Standards and the National Physical Laboratories were installed at all stations. Black paper and colored blotting papers are especially sensitive because of their low heat capacity and relatively high absorption. They are limited on the high exposure side because of the slight margin between charring and conflagration. They are important where the effective aperture or focal ratio of the ball of fire is weaker than F/10 or where strong filtering is used to examine spectral distribution. Papers inside of 1000 meters were generally filtered or shielded, except where dead white or fire-resistant

paper were used. So far no satisfactory fire-proof paper has been found.

Textiles

Black and white cotton sock material, white twill and woven fabrics were used for their uniform high or low reflectance throughout the spectrum. Wool cloth with forestry green rayon lining, olive drab and khaki worsted, flannel and nylon were included because of their low reflectance in the blue and the sharp transition to high reflectance at about 6000Å. Blue chambry was the only light blue reflecting woven material available.

Plastics

The Bureau of Ships near-infra-red filter material was used plain and mounted on glass; also plastic filters for separate portions of the visible spectrum were available. A supply of 1/16- and 1/8-inch lucite was used to pass the entire visible spectrum and to cut off below 3000Å and above 3 $\mu$. Cellulose acetate in thin sheets of about 0.01-inch thickness also served this purpose where smaller heat capacity was required especially in the case of the more distant stations. Vinylite and phenolics were not included.

Glass

Glass plates for use as filters were obtained from the Corning Glass Company. The filters cut off various broad

spectral regions from the receivers behind them. The spectrum was divided by filters into the following regions:

$$\lambda > 2000\text{Å}$$

$$\lambda > 3000$$

$$\lambda > 5000$$

$$3000 < \lambda < 4000$$

$$3000 < \lambda < 6000$$

$$\lambda > 7000$$

Behind each filter was exposed a set of receivers including heat sensitive papers, cloths, and metal foils.

Wax

Paraffin wax was used in the form of carbon paper: a thin opaque coat on tissue paper.

Paint

Standard paints on plywood were set up with and without filters. The colors included white, black, red, green, clear and blue.

Rubbers

A limited number of standard Navy rubbers were obtained.

## EQUIPMENT

The materials mentioned were, in general, mounted on thermal plaques about one foot square. It was recognized that each specimen should be in patches several inches on a side, but the small test area available precluded such sizes.

The plaques were made of 1/16-inch aluminum. On the face was a layer of canvas on which were spread the materials which acted as receivers. Some plates carried glass filters held on with brass clips. Loose ends of the receivers projected out to give an unfiltered reading. The brass clips were softened with heavy rubber strips to protect the glass and to serve as rubber receivers.

Some plates had plastic covering instead of glass. The receivers were laid on in overlapping horizontal strips so that about one centimeter of each was exposed to the radiation. Over part of these at right angles ran a set of plastic filters for red, infra-red, blue, green and yellow in the form of one centimeter strips. These were held in place by a cover plate of 1/16-or 1/32-inch lucite.

At the inner station, bricks of lead and zinc were set out. Sharp corners at holes drilled on the front side were softened to an extent determined by the radiation received.

A ball of fire 200 meters in diameter subtends an

angle at 2000 meters equivalent to an aperture or focal ratio f/10. This corresponds to an exposure of about 10 calories per $cm^2$. Since many receivers show marked effects at such energy doses, there was an opportunity to obtain detail on the distribution of light over the surface of the fireball.

An aluminum plate with 1/16-inch holes in three columns of eight holes each with about one inch between centers was backed with a wooden board which was perforated over the holes. Behind each hole were air spaces 1/2 and 1/4 inches deep. Behind this space was a set of receivers to cover all ranges of intensity and color available. Thus there was a set of pin-hole images formed of aperture f/4 and f/8.

## CALIBRATION

There are two main ways of evaluating the results of the exposures. One is by measuring the thermal and optical properties of the receiver and then computing the energy required to produce the effects observed. The other is to compare the actual effects with those on similar receivers subjected to a measured exposure using an artificial source designed to simulate the bomb burst. In general, except for thin uniform metal foils, only the latter method is practical.

In this method, light from a high-intensity carbon arc collimated in a 24-inch Navy searchlight was used. The collimated beam was concentrated on a sample of the material to be calibrated by means of another 24-inch searchlight mirror. The sample was driven through the focus at an accelerated rate so that all gradations of heating effects occurred. The beam intensity was measured with thermocouples so that the energy input could be computed. An iris on the searchlight could be used to reduce the energy in the beam and a smaller rate of travel could be chosen to compensate. In this way reciprocity corrections were obtained. After the test, as expected, a whole series of new calibrations were required to simulate field conditions for

cases of interest. The calibrations obtained in advance served only to indicate which materials to use and to give a preliminary estimate of the results.

## COLLECTION OF PLAQUES AFTER EXPOSURE

The thermal materials set out on Engebi and Aomon-Bijiiri were left covered with waterproof paper until the day before the tests. The materials were collected two or three days after the tests. On Muzin and Kirinian and also on Rojoa the plaques were set out uncovered two or three days before and collected the day after the test. Thus, the exposed time was nearly the same in all cases although weather conditions were different.

On the islands downwind from Aomon, Bokonaarappu, Aitsu, and Rujoru the plaques were uncovered several days before the test. Due to inaccessibility because of contamination they remained uncovered several days after the test. The increase of weathering was not marked.

All plaques showed signs of moisture and the condition of dryness at the moment of burst was unknown. This limits the exactness of the data and in many cases only a lower limit to the radiation can be obtained. The seriousness of this limitation should be investigated by calibration under various degrees of dampness.

The materials exposed on Engebi were recovered to within 1200 yards of the zero point. Some pieces closer to the zero point were found, but their condition was not

suitable for reliable estimates with the possible exception of lead and zinc blocks. The general conclusion from a consideration of the recovery was that it is desirable to reduce the sail area of specimens and to brace with diagonal compression members to cut down wind effects and destruction.

Casual inspection of close samples indicates that heat effects do not become increasingly severe at the rate expected within 1500 yards. Presumably, this is due chiefly to the shielding by the cloud of dust which envelopes the materials while the ball of fire is still radiating.

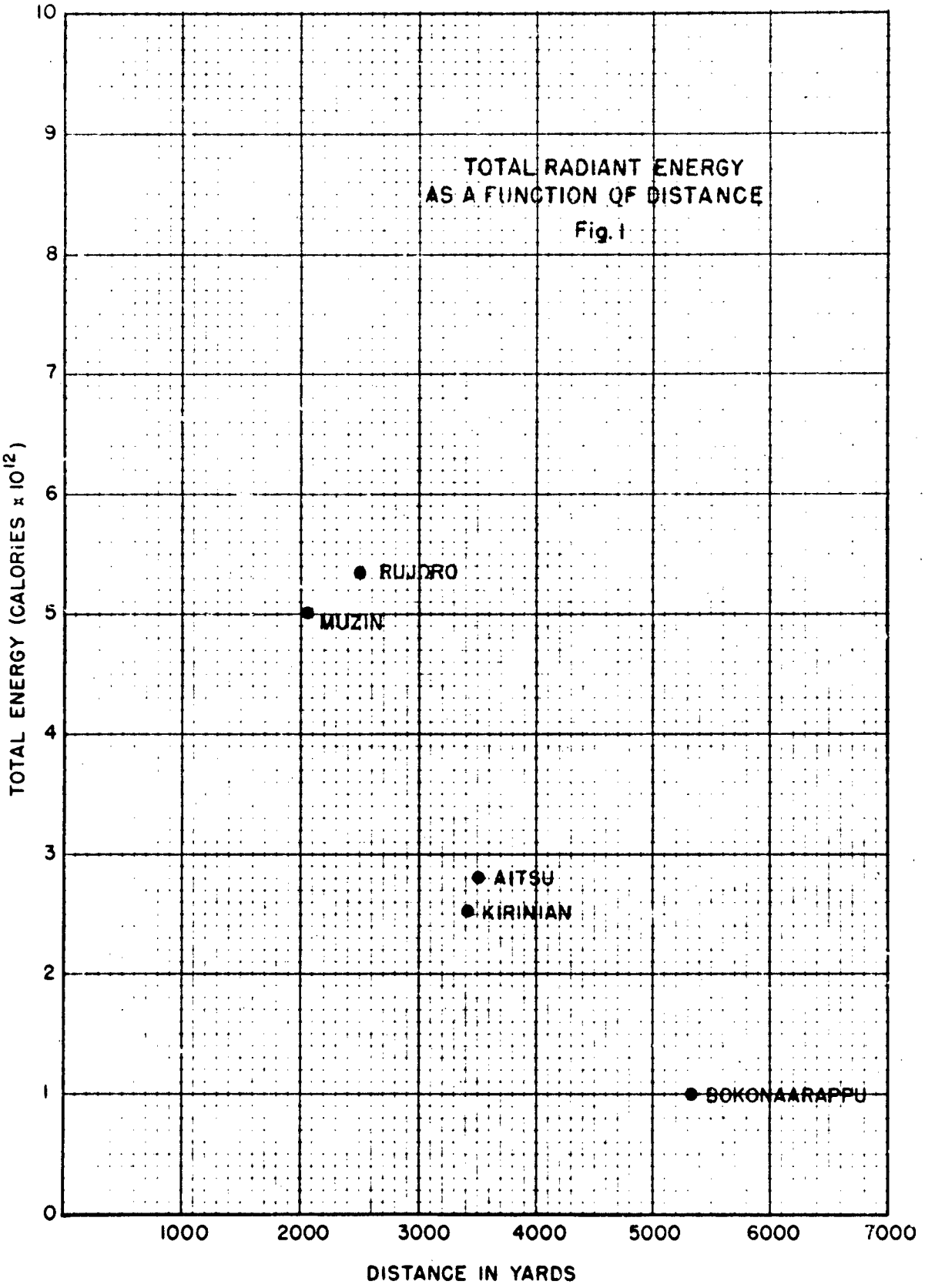
Plaques were recovered from Muzin (2000 yards) and Kirinian (3500 yards) and a beginning has been made in evaluating these results. A preliminary value of $4 \times 10^{12}$ calories or 4000 tons of TNT equivalent of energy radiated from the X-ray bomb was obtained. The calibrations used were inadequate and there is an uncertainty of about 50 per cent in the figures mentioned. The more distant station (Kirinian, 3450 yards) shows a lower radiation than would be expected from the nearer one (Muzin, 2000 yards) if the inverse square law applied. This suggests atmospheric attenuation, but it could also be explained in part by increased reflection from the broad beach on Muzin where the plaques were installed.

The materials exposed on Aomon were recovered to within

1000 yards of the zero point. Two lead and zinc blocks and two pin-hole receivers were recovered from stations at 250 and 330 yards. Even where energy values are unreliable it may be possible to give an estimate of the effective size of the ball of fire. Crude tentative measurements from the pin-hole receivers give values of about 200 yards for the radius. This is a strong corroboration of the suggestion that most of the radiation comes from the later stages of the ball of fire when it has become cool, large, and almost stationary in size.

The plaques on Rojoa (1800 yards) and on Rujoru (2500 yards), Aitsu (3500 yards), and Bokonaarappu (5300 yards) would have made an excellent series except for the disturbance of moisture from rain, spray or dew. In spite of this they constitute valuable data. Some specimens would dry quickly and some, such as plastics, would be relatively insensitive to moisture.

There is no justification for plotting all the rough data to date as though the numbers were comparable. However, when points are so plotted as in Figure 1, a trend in total energy integrated over a sphere is found. It is as though the energy was being reduced according to an exponential function of distance with a reduction factor due to absorption of 0.4 per mile. In combination with the


TOTAL RADIANT ENERGY
AS A FUNCTION OF DISTANCE
Fig. 1
TOTAL ENERGY (CALORIES x $10^{12}$)
DISTANCE IN YARDS
RUJORO
MUZIN
AITSU
KIRINIAN
BOKONAARAPPU
0
1
2
3
4
5
6
7
8
9
10
1000
2000
3000
4000
5000
6000
7000

observations on effective fireball size this suggests that a large fraction of the energy is in the infra-red beyond $2\mu$ .

A number of plaques were set out in the second test so that a flat side was exposed. The plaques were mounted on vertical iron pins so that they were free to turn in a strong wind.

When recovered, all but the most distant of these "flags" had turned. The thought was to get an idea of the time distribution of the radiation. If the side first exposed was more affected by radiation, then presumably the early phases, up to the time of arrival of the blast wave, dominated.

This was found to be the case at distances to within 1200 yards of the zero point. The burning on the side finally turned toward the blast was very slight. Before regarding this evidence as conclusive it will be necessary to consider the cooling effect of the high winds accompanying the blast and the tendency to blow out fires. The dust cloud must have had an effect and above all the cloud chamber effect reduced the effectiveness of the later stages after the passage of the shock front.

The definite conclusions that burning took place within two seconds of the detonation can nevertheless be drawn.

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## CONCLUSIONS AND RECOMMENDATIONS

The mass of material available for profitable study is gratifyingly large. It must be treated as a whole before a satisfactory picture of radiant energy effects can be presented.

The numerical results now at hand are qualitative, but more definite information can be obtained from the material at hand. The information to be expected will include a value for the total energy radiated from the bombs X-ray and Yoke; the effective size of the ball of fire; the effective duration of the radiation; the absorption of radiation in thicknesses of several miles of humid atmosphere; the qualitative integrated spectral composition of the radiation; the reaction of numerous important materials to the radiant energy as a function of distance from a bomb burst, at low elevation, on dusty terrain, surrounded by tropical water.

A preliminary value for the total energy radiated from the bombs on X-ray and Yoke is given as $4 \times 10^{12}$ calories. This is equivalent to about 4000 tons of TNT. The error in this determination may be as high as 50 percent. Readings from both bombs were averaged. The data so far are not sufficient to differentiate between the two bombs. The effective diameter of the ball of fire is about 200 yards.



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