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# (9) DIRECTOR OF SHIP MATERIAL TECHNICAL INSPECTION REPORT.

[redacted] (Final).

AD No. 366894

# FINAL REPORT

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Defense Atomic Support Agency
Washington, D. C. 20301

(6) OPERATION CROSSROADS.

## TEST ABLE AND TEST BAKER [U]. (8)

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~~By Authority of~~ DASASC-3 memo 29 Oct 56
By ............ Date 20 July 62

[redacted]

(11) 14 Mar 47
(12) 66p.
(14) XRD-1

OPERATION CROSSROADS
JOINT TASK FORCE ONE

[redacted]





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(193600)

**CONFIDENTIAL** [redacted]

DIRECTOR OF SHIP MATERIAL
JOINT TASK FORCE ONE

14 March 1947

FINAL REPORT

~~The final report of the Director~~ of Ship ~~Material is submitted herein. It~~ This report is an overall summary of the Director of Ship Material organization, responsibilities, and activities together with highlights on the observed results of Operation Crossroads. Pertinent observations, conclusions, and recommendations of both a specific and general nature covering the most significant aspects of Operation Crossroads are submitted. The Table of Contents will make apparent the nature and order of presentation of the subject matter covered.

Detailed results, discussions, and recommendations will be found in the reports of the individual activities under the Director of Ship Material. These reports are listed as enclosures hereto.

The importance of Operation Crossroads in its implications on future naval warfare, national security and national defense cannot be escaped and consequently comments on these subjects also have been made.

T. A. Solberg
T. A. SOLBERG

"This document contains information affecting the National Defense of the United States within the meaning of the Espionage Laws, Title 18, U. S. C., Section 793 and 794. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law."

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GROUP 3
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Not automatically declassified.
1 JAN 1955



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# I. INTRODUCTION

## A. ORGANIZATIONAL POSITION IN TASK FORCE

The organization of the Director of Ship Material was a major division, operating under the Deputy Commander for Technical Direction, Joint Task Force One. The title, Director of Ship Material, was chosen as best delineating the broad range of duties and responsibilities visualized at the time the Task Force Organization was formulated. Additional duties and responsibilities, not visualized at the time of inception of the Task Force Organization, arose in the target area and were assigned to or taken over by the Director of Ship Material.

Classification (~~Cancelled~~) (Changed to SECRET)
By ~~Authority~~ of Joint Chiefs of Staff (Action 15 Apr 49)
By [illegible] Date 27 November 1951

[redacted]

## B. RESPONSIBILITIES

The Director of Ship Material was assigned the following responsibilities:

1. Planning those aspects of Operation Crossroads which involved the exposure of the target ships and various types of equipment, arranging the exposure and placement of test specimens and materials, the placing of instrumentation required by other groups, and satisfactory locations for the animals. This planning required collaboration with all other groups of the Task Force in order to determine the overall requirements. The Director of Ship Material coordinated the activities of these groups and the operational requirements of the forces afloat with respect to the target ships. The loading of all target vessels was planned so that the drafts at the time of the tests would approximate battle conditions. Special means of anchoring and mooring target vessels were evolved in conjunction with Commander Task Group 1.2 (Target Vessels).

2. Preparation of all target vessels for the tests. Instructions were issued to the various Naval Shipyards regarding the loading and securing of equipment, the installation of instrumentation arrangements, etc. Tests and inspections were conducted before Test Able, to determine the condition of the target vessels in order to avoid uncertainty in interpreting the results of the tests. These phases of the organization's activities are discussed in detail in the various group instruction and preparation booklets, in the group histories, and in the Director of Ship Material History.

3. The initial reboarding and preliminary inspection of all vessels after each test to make preliminary estimates of gross damage, to determine any necessary immediate salvage measures, and to determine the suitability of the vessels for reoccupancy by the crews.

4. Detailed inspections of the damage to the target vessels and the evaluation of the results of these inspections. This included the effect on mobility and fighting power. Factual data, as complete as possible under the condition encountered, were obtained by qualified technical observers. Essential photographs of conditions before and af-

ter the tests were obtained. The scope of this phase is indicated by the fact that about 20,000 still photographs were taken by the Director of Ship Material Groups. In addition, aerial and motion pictures were taken.

5. Repair of certain damage after Test Able was comtemplated and actually carried out. This was done to make the conditions for Test Baker more satisfactory and also because restoration of power was required, where practicable, for the conduct of after explosion tests on equipment and machinery units. Such repairs and subsequent tests assisted in making an evaluation of the effect of Test Able on military efficiency.

6. In addition, the Director of Ship Material and his groups assisted in planning the arrangement of vessels in the target arrays. One of the major requirements for each test was that the result must show gradations of damage from major to negligible. This required consideration of probable errors in the placement of the air burst. Observed damages indicated that this gradation was achieved.

## C. ORGANIZATION

### 1. GENERAL

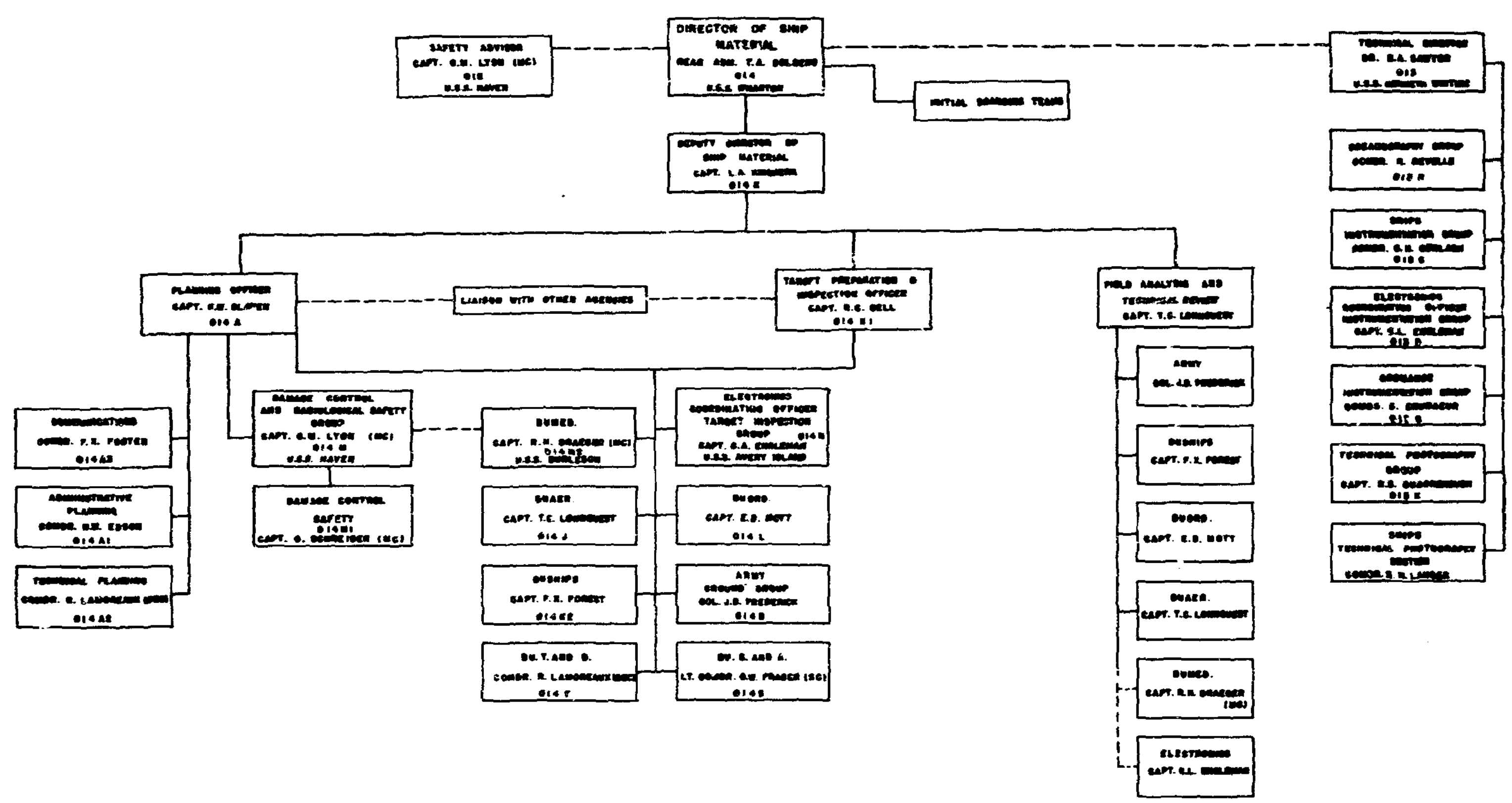
The Director of Ship Material Organization comprised technical groups from the Bureaus of Ships, Ordnance, Aeronautics, Yards and Docks, Medicine and Surgery, and Supplies and Accounts of the Navy Department, and the technical groups representing the Army Ground Forces. In addition, two representatives of the Maritime Commission were present to observe the results of the tests on ships built by the commission.

It soon became evident that in order to accomplish certain aspects of instrumentation for all groups of the Task Force, it would be desirable to place all the electronic requirements involved in any instrumentation project under one group. The Director of Ship Material agreed to expand the Bureau of Ships Electronics Group to carry out this work. The Bureau of Ships Electronics Officer was made the Electronics Coordinating Officer and as such served primarily under the Technical Director and secondarily under the Director of Ship Material.

### 2. DIAGRAM

A diagram of the Director of Ship Material Organization is on page 5.

# DIRECTOR OF SHIP MATERIAL ORGANIZATION



D. REPORTS

1. GENERAL

Enclosures (A) through (I) are the principal reports of of the activities under the Director of Ship Material. All of these, except enclosure (E), have been completed. It is anticipated that the components of enclosure (E) will be completed on the dates indicated. The reports discuss the effects of the atomic bomb tests on materials and equipment within the cognizance of the individual groups. The report of each group included factual data, photographs, general discussions, conclusions, and recommendations in summarized form. Additional information, describing the characteristics of the burst and other phenomena, is available in the reports submitted by other activities of Joint Task Force One. It is considered that the completed reports of the individual activities plus the report of the Medical Research Section, Bureau of Medicine and Surgery, contain all of the information which is required for use in conjunction with this FINAL REPORT.

The Bureau of Ships Group is tabulating damage to individual ships for each test. These tabulations in most cases will be separate booklets covering each vessel. Certain vessels which received minor damage are discussed in one booklet.

The Director of Ship Material coordinated the work of all groups in the preparation of reports and discussed the subject matter in considerable detail with the group heads. General concurrence with the conclusions in these reports was reached. Therefore, the separate reports are to be regarded as the detailed portion of the Director of Ship Material report.

Attention is invited particularly to the summary report of the officer in charge of the Bureau of Ships Group, (Captain F. X. Forest, USN). This report is considered to be outstanding in its completeness and thoroughness. Because of the interrelation of ships structure with all types of equipment, it contains significant material from reports of other activities under the Director of Ship Material. This made it possible to present a more complete summary of the effects on ships as a whole. It also contains a presentation of the radiological aspects which affect ship's structures and personnel.

2. LIST OF ENCLOSURES

(A) Bureau of Ships Group.

(1) Final report Test Able and Test Baker. Two volumes.

(2) Reports of damage to individual ships. 133 volumes.

(3) Special Reports. 16 volumes.

(B) Army Ground Group, Final Reports of Atomic Tests.

Volume One - GENERAL

Volume Two - ENGINEER CORPS

Volume Three - SIGNAL CORPS

Volume Four - ORDNANCE CORPS

Volume Five - CHEMICAL WARFARE SERVICE

Volume Six - QUARTERMASTER CORPS

Volume Seven - AIR CORPS

(C) Bureau of Aeronautics Group. Final Report for Tests ABLE and BAKER. One Volume.

(D) Bureau of Ordnance, Material Group, Final Report for Tests ABLE and BAKER. Five Volumes.

(E) Bureau of Medicine and Surgery Research Group, Final Reports to follow in accordance with following schedule:

(1) Overall report - Analysis and Correlation of detailed appendices. September 1947.

(2) Appendices.

1. Bacteria, effects on. January 1949.
2. Biologicals, effects on. January 1948.
3. Blast injuries. July 1947.
4. Blood Chemistry. March 1947.
5. Carcinogenesis. January 1950.
6. Collective protectors. July 1947.
7. Flashburn protection. Two reports. June 1947.
8. Genetic effects. Four reports. January 1948 to January 1949.
9. Hematology. Three reports. June 1947 to January 1949.
10. Effects on medical and dental supplies and equipment. July 1947.
11. Pathology. Five reports. March 1947 to January 1950.
12. Photography. June 1947.
13. Physical data. Six reports. April 1947 to January 1948.
14. Psychotic Goats. June 1947.
15. Residual radioactive effects.

16. Soils, effects on. June 1947.

17. Statistics - Analysis and discussion of the validity of the data. January 1948.

(F) Electronics Coordinating Officer Ship Preparation and Target Inspection Group. Final Report for Tests ABLE and BAKER. Two Volumes.

(G) Bureau of Yards and Docks Group. Final Report for Tests ABLE and BAKER. One Volume.

(H) Bureau of Supplies and Accounts Group. Final Report. One Volume.

(I) Report of Damage to Maritime Commission Built Vessels of the Target Arrays of the Atomic Bomb Tests ABLE and BAKER. One Volume.

(J) Report on Decontamination of Target Vessels, Test BAKER. One Volume.

(K) Director of Ship Material, History on RECLAIMER - Test BAKER. One Volume.

(L) Director of Ship Material History. Three Volumes.

## II. RESULTS

### A. INTRODUCTION

#### 1. GENERAL

The energy released by the atomic bomb used at Bikini was equivalent, in terms of heat, light, kinetic energy and pressure, to that from about 20,000 tons of TNT. At distances greater than 500 yards the only detectable differences between the two types of explosions would be in the visible and ultraviolet light and the nuclear radiations from the atomic bombs.

It was the scale of these explosions, as produced by the explosive used, which made the scales of damage and mechanical effects so different from war damage heretofore observed. Damage imposed on a vessel by conventional explosives tends to be confined to a small area. One destroyer for instance was broken in two by a near miss straddle amidships. The forward half floated and showed little damage except the severe damage to the underwater hull and to machinery near the midship section. The damage resulting from the atomic bomb tests affected the whole ship structure generally. The severe damage noted in any particular area of a ship was no greater than that observed with conventional explosives. However, the fact that the damage was distributed more generally throughout the ship structure should serve to place emphasis on design refinements involving the whole structure as a unit, as well as on localized areas which exhibited weaknesses.

Tests Able and Baker far exceeded any previous application of powerful explosives against ships. A significant feature of this type of attack is that it subjects, practically simultaneously for a very short period, all parts of the exposed ship's structure to a combination of extremely large forces. These forces vary somewhat over the length of a ship oriented in the direction of the blast.

Test Able imposed high air blast pressures, high wind velocities, extreme light flash, and high temperature radiation, plus the added personnel incapacitating effects of neutron and gamma ray bombardment.

Test Baker was characterized by: violent underwater shock pressures; unusual vertical, horizontal, and angular displacements at high accelerations from wave action; damage from the impact of large volumes of water from both horizontal and vertical directions; air blast pressure and wind velocities of much lower order than in Test Able; nuclear radiation which was composed of the highly personnel incapacitating bombardment of gamma and beta radiation from the enveloping base surge; and the persistent radiation from explosion products deposited by the surface gravity waves, base surge, falling water and mist. These explosion products contained gamma, beta and long life alpha emitters.

2. TYPES OF DATA OBTAINED.

The Bikini tests were conducted as scientific experiments of great magnitude. The data obtained include: observations and photographs of mechanical damage; and measurements of structural responses to factors such as air blast, underwater shock, surface gravity waves, and falling water.

Data are available from the Technical Director for integration into the many potential detailed studies. Such information includes observations of the following: distances; angles of attack; peak values and duration characteristics of air blast, secondary wind velocities, and underwater pressure; and measurements concerning heat, light, waves, nuclear radiations, and other explosion phenomena.

A consideration of the above factors indicates the extent and complexity of the technical and scientific studies which must be made before a complete evaluation of the tests can be made. These factors also indicate the necessity for integration and coordination of the studies by the various groups assigned. Final design modifications and decisions must not be made, in many cases, on the basis of the analysis of the results obtained from one seemingly cognizant group such as ship designers or ordnance designers. Instead such modifications must be made after an evaluation of all the applicable results which were obtained by other technical and scientific groups.

3. ANALYSIS OF RESULTS.

Although it never was contemplated that complete analysis would be undertaken by personnel assigned to the Task Force, some effort has been expended in an effort to correlate observed damage with basic instrumentation data. Complete analysis using all available data, is a long term project which must be undertaken by cognizant activities, if the maximum practicable results are to be obtained. Individual groups in the Director of Ship Material organization have completed final reports which are in great detail. The reports are considered to be sufficiently complete for the purpose of future detailed study by cognizant design agencies.

4. CONSIDERATION OF THE EFFECTS OF VARIATION IN TEST CONDITIONS.

There is a tendency to limit the evaluation of results to the conditions of the tests as held. It is necessary, however, for preparedness and future planning, to consider the possibilities under different conditions. Variables to be considered in the use of atomic bombs include, among others, the height or depth of burst and the efficiency of the bomb.

Preliminary calculations indicate that the burst in Test Able was not detonated at the optimum height for producing the greatest range of damage from air blast. It appears that the damage area would have been greater with a somewhat greater height of detonation. Similarly, the character of Bikini Lagoon and other considerations did not permit detonation of the underwater burst at the depth which would produce the maximum range of underwater shock damage to structure and mechanical equipment. Variation of the depth of burst also would have an appreciable effect on the phenomenon of the base surge with its accompanying radiological aspects. The planned depth of an underwater burst therefore would depend upon which of these effects it was desired to maximize and on the depth of water in the selected target area. The analysis of the variations of phenomena to be expected as a result of such changes in test conditions is beyond the scope of this report.

The target array was designed to obtain a gradation of damage from sinking to negligible. The inaccuracy in the placement of the air burst militated somewhat against gradations in damage among types and affected to some extent the completeness of the instrumentation results obtained. However, the care with which the array was planned insured satisfactory over all results, even with a deflection of the magnitude experienced.

If the bomb in the air burst had been detonated at the intended location, the major vessels which were grouped near the center of the array would have been more badly damaged. Approximately five more vessels would have been within a range of heavier damage, and a better gradation of damage within types of vessels might have resulted.

The planned distance of the SARATOGA from the underwater burst was between 450 and 500 yards. Actually, because of wind conditions at the time of burst, the SARATOGA was only 384 yards distant. If the SARATOGA had been at the greater distance, she might not have sunk, or her sinking might have been delayed long enough to enable beaching. Had this occurred, much more information concerning damage to this vessel would have been obtained.

## B. EFFECT OF THE TESTS.

### 1. GENERAL EFFECT.

In this table of the effect of the bursts the following definitions of damage to material apply:

Extreme damage is that which completely destroys the function of the material so that replacement rather than repair is required.

Heavy damage is that which does not destroy completely the function of the material but which requires extensive repairs and possibly replacement.

Moderate damage is that which permits material to continue its original function in a weakened or less efficient condition. Such damage would permit continuous operation but would require repair at the first opportunity.

Light damage does not affect particularly the function of the material but may cause minor secondary interference or difficulties. Repair is required when opportunity presents.

Negligible damage does not affect operation or require repair. It is, however, visible and indicates that a damaging force has been present.

The general effects of the burst are as follows:

| TEST | | Combined effects of Light, Heat, Shock, Blast, Wind and Wave effects. | Effect of Radioactivity |
|---|---|---|---|
| ABLE | Material | Extreme to about 800 yards.<br>Heavy to about 1000 yards.<br>Moderate to about 1400 yards.<br>Light to about 1700 yards.<br>Negligible beyond 1700 yards. | Negligible |
| ABLE | Personnel | Serious casualties to exposed personnel inside 2000 yards. | Severe casualties to about 1800 yards for topside personnel; to about 1400 yards for below deck personnel. |
| BAKER | Material | Extreme to about 800 yards.<br>Moderate to about 1100 yards.<br>Light to about 1300 yards.<br>Negligible beyond 1300 yards. | Severe radioactive contamination to about 4000 yards for vessels within the confines of the base surge and radioactive mist. Vessels beyond these limits would not be appreciably affected, dependent on wind conditions. |
| BAKER | Personnel | Serious casualties to about 900 yards. | Extreme casualties to exposed personnel within the limits of the base surge and radioactive mist which in this test was approximately 4000 yards. Personnel beyond these limits would not be appreciably affected except in the downwind section. Below deck personnel would have suffered numerous casualties out to 2000 yards and probably as far as 4000 yards. |

## 2. SUMMARY OF RESULTS TO MILITARY EFFECTIVENESS BASED ON MATERIAL DAMAGE.

In each of the following categories of the effect on military effectiveness there is listed:

(1) The name of the ship.

(2) Its approximate distance from the burst.

(3) For Test Able, approximate values of air pressure corresponding to the distance; these values are substantiated fairly well.

(4) For Test Baker, approximate values of underwater shock pressure. These values are not well substantiated at this time but are listed so as to indicate the order of magnitude of the forces involved.

Some of the data used have been abstracted from the preliminary report of the Technical Director, which discusses in detail the many considerations involved in determination of accurate values of underwater shock pressure.

| | Test Able | Test Baker |
|---|---|---|
| a. SHIPS EXPOSED: | | |
| Afloat: | 70 | 70 |
| On Beach: | 18 | 18 |

b. SUNK

**Test Able**

| | Distance Yards | Air Blast Pressure psi |
|---|---|---|
| (APA57) GILLIA[illegible] | 117 | ___ |
| (APA69) CARLISLE | 456 | 64 |
| (CL-J) SAKAWA (26 hours after test) | 511 | 50 |
| (DD411) ANDERSON | 618 | 32 |
| (DD367) LAMSON | 767 | 20 |

**Test Baker**

| | Distance Yards | Underwater Shock Pressure psi |
|---|---|---|
| LSM(60) Bomb Carrier | 0 | 4500 |
| (BB33) ARKANSAS | 250 | 3450 |
| (SS386) PILOTFISH | 320 | 3450 |
| (CV3) SARATOGA (8 hours after test) | 380 | 2700 |
| (YO160) Concrete barge | 460 | 2100 |
| (BB-Jap) NAGATO (5 days after test) | 800 | 1100 |
| (SS184) SKIPJACK (LH) | 810 | 1090 |
| (SS308) APOGON (HH) | 860 | 1040 |

c. TEMPORARILY IMMOBILIZED OR SERIOUSLY DAMAGED:

**Test Able**

| | Distance Yards | Air Blast Pressure psi |
|---|---|---|
| (CVL22) INDEPENDENCE | 635 | 30 |
| (BB36) NEVADA | 700 | 24 |
| (BB33) ARKANSAS | 700 | 24 |
| (CA24) PENSACOLA | 800 | 18 |
| (CA25) SALT LAKE CITY | 958 | 12 |
| (DD410) HUGHES | 970 | 12 |

**Test Baker**

| | Distance Yards | Underwater Shock Pressure psi |
|---|---|---|
| (LCT1114) (Capsized during test) | 400 | 2500 |
| (APA81) FALLON | 530 | 1850 |
| (DD410) HUGHES | 620 | 1500 |
| (APA85) GASCONADE | 670 | 1400 |
| (LST133) | 680 | 1380 |
| (CA24) PENSACOLA | 750 | 1200 |
| (ARDC13) Drydock (Capsized 11 days after test) | 1230 | 580 |

| Test Able | | | Test Baker | | |
|---|---|---|---|---|---|

d. NOT IMMOBILIZED BUT MILITARY EFFICIENCY SERIOUSLY IMPAIRED:

| | Distance Yards | Air Blast Pressure psi | | Distance Yards | Underwater Shock Pressure psi |
|---|---|---|---|---|---|
| (SS305) SKATE | 440 | 69 | (BB34) NEW YORK | 920 | 850 |
| (YO160) Concrete Barge | 570 | 38 | (DD402) MAYRANT | 930 | 840 |
| (APA77) CRITTENDEN | 660 | 35 | (BB36) NEVADA | 1050 | 670 |
| (ARDC13) Concrete Drydock | 820 | 17 | (BB38) PENNSYLVANIA | 1160 | 580 |
| (APA79) DAWSON | 900 | 14 | (CA25) SALT LAKE CITY | 1180 | 570 |
| (DD404) RHIND | 1040 | 10 | | | |
| (LST52) | 1550 | 4 | | | |

e. MODERATE DAMAGE WITH MILITARY EFFICIENCY NOT SERIOUSLY IMPAIRED:

| | Distance Yards | Air Blast Pressure psi | | Distance Yards | Underwater Shock Pressure psi |
|---|---|---|---|---|---|
| (BB-Jap) NAGATO | 900 | 14 | (APA65) BRISCOE | 910 | 860 |
| (APA66) BRULE | 1050 | 10 | (APA66) BRULE | 920 | 840 |
| (DD390) RALPH TALBOT | 1160 | 7 | (SS305) SKATE | 940 | 800 |
| (APA60) BANNER | 1250 | 7 | | | |
| (CA-Ger.) PRINZ EUGEN | 1300 | 4 | | | |
| (BB34) NEW YORK | 1643 | 4 | | | |
| (BB38) PENNSYLVANIA | 1645 | 4 | | | |
| (APA68) BUTTE | 2000 | 3 | | | |
| (CV3) SARATOGA | 2400 | 3 | | | |

f. NEGLIGIBLE DAMAGE:

| | |
|---|---|
| Remaining 43 ships afloat.<br><br>18 landing craft on the beach. | 47 ships afloat beyond 1250 yards; 1 of these, the DENTUDA, which was submerged for the test sank because of flooding which could have been controlled by the ships force.<br><br>Of the 18 craft on the beach, 8 were swamped or partially flooded. LCVP 10 apparently was washed off the beach and then sank. |

3. RESULTS TO MILITARY EFFECTIVENESS BASED ON COMBINED MATERIAL DAMAGE AND PERSONNEL CASUALTIES.

The above tables are based on material damage only. Considering personnel casualties also, the following approximations can be made. The figures given are tentative only. Further analysis is necessary to determine more exact ranges.

a. AIR BURST

(1.) Vessels within 1000 yards would be disabled by material failures but in a few cases would be able to steam at reduced speed. Personnel casualties would be very high. Consequently all vessels in this range can be considered unable to remain in operation with the task force.

(2.) Most vessels between 1000 and 1700 yard ranges would have considerable personnel casualties which soon would reduce mobility. Military efficiency would be impaired, seriously because of damage, and extended operation would be impossible.

(3.) Vessels beyond 1700 yards, would have lesser personnel casualties with moderate damage to material; operation with some reduction in efficiency would be possible.

b. UNDERWATER BURST

(1.) Vessels within 4000 yards, dependent on wind conditions, soon would be immobilized, regardless of damage received, because of radioactive effects on major portions of personnel.

## 4. DISCUSSION OF DAMAGE TO MATERIAL

The discussion of the observed effect of the test is divided into separate sections for Test Able and Test Baker. These sections are divided further into subsections. The first subsection discusses those general results which are applicable to all types of material. The remaining subsections discuss the effect of the tests on material under the cognizance of various activities under the Director of Ship Material. Hull, Machinery, Electrical, and most Electronic material are under the cognizance of the Bureau of Ships. Other materials are under the cognizance of the indicated activities. A brief description of the types of material in each category in this report follows:

(1) BUREAU OF SHIPS EQUIPMENT

(a) HULL refers generally to the ships structure and general arrangement.

(b) MACHINERY refers to main propulsion and associated units and to items of deck equipment such as power operated boat davits, steering and anchor gear.

(c) ELECTRICAL refers to generators, motors, switchboards, control panels, wiring, etc, regardless of units to which attached.

(d) ELECTRONICS refers to equipment such as radio, radar, and echo ranging equipment.

(2) BUREAU OF ORDNANCE EQUIPMENT refers to gunnery and torpedo installations, including fire control and fire control radar systems, and to all types of ammunition, explosives and incendiaries.

(3) BUREAU OF AERONAUTICS equipment refers principally to aircraft with all pertinent components.

(4) BUREAU OF YARDS AND DOCKS equipment refers principally to the three floating concrete vessels and to pontoon test units.

(5) BUREAU OF SUPPLIES AND ACCOUNTS material refers to various items of food, clothing, and equipment which were displayed for test.

(6) U. S. ARMY EQUIPMENT refers to items which were displayed for test purposes by the following activities of the Army: Engineer Corps, Signal Corps, Ordnance Corps, Chemical Warfare Service, Quartermaster Corps and Air Corps.

a. TEST ABLE

(1) GENERAL

There was little significant damage to material beyond ranges of the order of 1200 yards. The damage was similar in all type of ships but varied in degree with the different types. Damage to aircraft extended to approximately 2200 yards. It appears that refinements in design and some changes in materials may reduce the radius of damage to distances of the order of 750 yards, without seriously affecting the offensive characteristics of the individual types of ships. If final evaluation indicates the necessity for further reduction in this range of damage, this undoubtedly will involve reductions in the offensive power or other characteristics of the ship. There is, however, a limiting range within which it is not practicable for a ship to remain as an efficient fighting unit from a material standpoint; and a somewhat lesser range, of the order of 500 yards, within which ships generally cannot be expected to remain afloat. Improvements already incorporated on latest ship types and improvements currently underway must be considered in evaluation of the above.

Thermal effects on materials caused directly by high intensity radiation were observed out to 3700 yards. These were confined almost entirely to susceptible surfaces directly exposed to the burst of light. The exceptions were due to fires which spread from directly exposed objects. Scorching of organic material and blistering of paint was observed throughout the array. The mechanism by which some fires were generated is not understood and will require both further analysis and experimental work.

(2) BUREAU OF SHIPS EQUIPMENT

(a) HULL

The air burst produced general damage to exposed topside structure, but produced only negligible if any water shock effect and no crushing effect on ship structure, both of which had been predicted by some phenomenologists.

The principal damage in every case was caused by air blast pressure and its accompanying high wind velocity. Considerable analysis will be necessary in order to determine the relative effects of each. The wind velocity, for instance, measured 657 feet per second (395 knots) at a distance of 800 yards from the burst. Tremendous total pressure loads were exerted on flat surfaces normal to the blast out to 2000 yards. The SARATOGA elevator, which was designed to withstand a load of 100 tons, was subjected to a load of approximately 380 tons. Both elevators of the INDEPENDENCE, each weighing about 22 tons, were blown overboard, although they were locked in the raised postion. Photographs and instrumentation indicate that ships near the blast and oriented so as to present their broadsides rolled heavily. The RHIND, which was broadside at 1040 yards, rolled 16 degrees and was given a slight transverse bodily motion.

Orientation and shape of structure had considerable influence on damage. As would be expected, surfaces nearly parallel to the direction of burst generally were damaged less than were surfaces more nearly normal to the burst. Heavy damage occurred in certain locations not exposed to the direct blast as the result of the effects of deflection and reflection of the blast wave from directly exposed surfaces. Pockets or dead ends suffered particularly. These phenomena require further study.

Blast damage decreased rapidly with distance, although there were no gaps or marked discontinuities. This change is apparent over the length of an individual ship as in the cases of the ARKANSAS (29-18 psi), NEVADA (30-17 psi), SALT LAKE CITY (13-10 psi), PENSACOLA (21-13 psi), HUGHES (13-10 psi), CRITTENDEN (38-28 psi), SAKAWA (80-33 psi), and INDEPENDENCE (36-22 psi). The SAKAWA presented her stern to the blast and suffered severe topside damage from amidships aft. Decks were dished severely as observed from a distance. The front and top turret plates of the forward turrets also appeared to have dished perceptibly. Her sinking can be attributed to a vertical tear in the hull which initiated above water and extended below the water line. The tear was on the centerline at the stern. Progressive flooding ensued, and the vessel sank stern first.

The air burst caused extensive damage to the superstructure and to all types of exposed equipment on vessels within 1200 yards range. There was relatively little damage below decks, except in way of decks which had suffered deflection. Light bulkheads, stacks, boiler casings, masts, booms, cranes, rigging, ventilation ducts, gunshields, searchlights, radio and radar antennas proved highly vulnerable close in. Stacks on the CRITTENDEN, however, resisted the blast and suffered only minor damage. Watertight doors and frames were distorted so as to nullify their functions. The observed damage was not significant as regards general structural strength except in the cases of the CRITTENDEN and INDEPENDENCE. Evidence in the cases of sunken ships, of course, is lacking. The INDEPENDENCE is an aircraft carrier adapted to an existing cruiser hull. The results on these two vessels furnish material for many valuable design studies.

Eight submarines were exposed on the surface during this test. The SKATE, at about 450 yards, had her non-strength topside structure practically demolished but sustained no damage to her strength hull. The APOGON, at about 1000 yards, and the remaining six submarines at greater ranges from the burst suffered negligible damage.

(b) MACHINERY

Damage to mechanical equipment was confined largely to deck units. Much of this damage was solely a result of distortion of the supporting structure. Boiler casings were damaged in varying degrees out to 1600 yards. Much of this damage may be attributed to older design and methods of construction, as well as to deteriorated material. Newer design of air encased boilers, constructed from high strength materials, suffered relatively little damage and showed definite superiority with regard to materials and design over older conventional types. Boilers of most recent designs are built for even higher operating air pressures than were those on the target ships. It would be possible to determine theoretically what damage would have occurred had boilers of most recent design been exposed. Older boiler designs operate with the fire rooms under air pressure, generally known as closed fire rooms systems. Present designs have air casings around the boilers, the air encased space being under pressure and the fire room open and not under air pressure.

It is interesting to conjecture as to what would happened in the cases of boilers under operating conditions. Serious flare backs would have occurred in both the old and new boiler designs. Undoubtedly, serious personnel casualties would have occurred in the cases of closed fire rooms. In open firerooms with air encased boilers, flare backs would have occurred but with fewer personnel casualties. Operation would have been interrupted in air encased boilers during the time when the blast pressure exceeded furnace front air pressure. Newest designs therefore would have suffered to but a minor degree, and power source from the boilers would have been interrupted to a negligible degree.

Emergency Diesel generators, which were in operation on 15 surface ships at various distances, functioned throughout the test. This attests to the sturdiness and reliability of these units and justifies their installation as auxiliary or emergency power units.

(c) ELECTRICAL

Exposed electrical equipment and instruments were damaged badly to a distance of approximately 900 yards. Control panels switchboards, etc., were damaged by distortion of their light weight metal enclosures. Exposed electric motors stood up well, although in some instances connecting shafting was distorted by deck movements, thus making the unit inoperable.

(d) ELECTRONICS.

Damage to exposed electronic equipment was heavy out to 1200 yards and generally minor from 1500 yards to as far as 2200 yards. Protected units were undamaged except where located on or too close to bulkheads which were distorted sufficiently to damage adjacent and supported equipment.

The most serious damage was the heavy and widespread destruction and deformation of antennas and reflectors. Damage was primarily due to air blast although minor heat damage to plastic parts of fire control antennas extended to a greater range. Wire antennas suffered most, but large dish and bedspring type antennas also suffered widespread destruction.

Whip antennas, particularly spring mounted ones, and small heavy radar reflectors stood up well.

The major lesson of both tests from the standpoint of electronics is the need to redesign all types of antennas to withstand severe air blast and shock.

(3) BUREAU OF ORDANCE EQUIPMENT.

Fairly extensive damage occurred to topside ordnance equipment out to 1000 yards and in some categories beyond this. Director and gun shields were dished badly. Many Mark 14 and Mark 15 gunsights were damaged. Fire control radar antennae and supporting structure, searchlights, stable elements, and light guns were made inoperable. Structural distortion caused misalignment of small caliber batteries. The light structures enclosing directors and mounts were distorted. However, the equipment within such enclosures, including delicate mechanisms, was still operable. Damage to guns, heavy equipment, and optical systems was light, but the damage to radar equipment and power supplies reduced the effectiveness of fire power to a large degree. Range finders and secondary optical systems remained operable in practically every instance. The damage from blast did not affect equipment on the inside of turret structures, even though all access was open.

Navy ammunition, including mines, torpedoes and depth charges, was not affected appreciably. There were no cases of detonations resulting from the burst. Low order explosions on the INDEPENDENCE occurred in locations where fires eventually had penetrated about four hours after the burst. These explosions probably were charged torpedo air flasks which had been heated by the fires. Photographs indicate possible explosions of exposed pyrotechnics in the ANDERSON. Refinements in the design of ammunition, in general, do not appear to be necessary.

(4) BUREAU OF AERONAUTICS EQUIPMENT.

Aircraft exposed topside to an atomic bomb air burst will be blown overboard or completely destroyed if within 1300 yards distance, with damage diminishing to light beyond 2200 yards. The most practicable means for reducing damage to aircraft is by stowage below decks. If protected by stowage in intact hangar spaces or in compartments free from openings which would admit blast effects, aircraft will be substantially undamaged at any range at which the supporting vessel will survive. Two PBY-?H flying boats moored at 2700 and 3300 yards from the burst sustained major damage to their above water hulls, but remained afloat. There was little damage to other components of these seaplanes. Modifications to aircraft for the purpose of increasing resistance to blast damage appear to entail unacceptable penalties on performance, except in minor instances such as canopies and drop tanks. Radiological effects on material are not significent. Aviation ordnance equipment suffered no damage.

(5) BUREAU OF YARDS AND DOCKS EQUIPMENT.

The damage to the concrete floating structures was confined mainly to blast damage on the topsides. The YO 160, a concrete oil barge, at approximately 450 yards, suffered severe top-side damage, having all structure above the main deck damaged in various degrees. The ARDC 1?, a concrete floating drydock, at approximately 800 yards, suffered moderate damage evidenced by the cracking of concrete, which was distributed fairly evenly over the surface of the dock floor. The forces imposed also produced a crack slightly below the water line which caused slow flooding and listing. This crack was repaired hastily and temporarily to make the craft available for Test Baker.

The YOG 83, a concrete gasoline barge, at approximately 1000 yards received negligible damage.

(6) BUREAU OF SUPPLIES AND ACCOUNTS EQUIPMENT.

There was little effect on materials exposed topside. Such materials were limited in number to avoid duplication of exposed Army items.

Bureau of Supplies and Accounts materials stored below decks suffered no deleterious effects. Some materials located near the burst and containing sodium compounds showed transient or temporary radioactivity which subsided rapidly. Inside 700 yards there would have been some danger in con sumption of unsealed foods, such as those in vegetable lockers anf flour bins, because of the possibility of radioactive dust deposits. Exposed foods in sealed containers were safe for use within 24 hours.

(7) U.S. ARMY GROUND GROUP EQUIPMENT.

There were no significant differences between the effects on Army equipment and similar items of Navy equipment.

Damage to heavy equipment such as tanks and guns was similar to that of Navy heavy ordnance equipment. Lightly constructed exposed components were deformed or broken, and inspection plates failed.

Unarmored vehicles and other items of light construction such as searchlights and electronic equipment were damaged severely out to 1200 yards.

Heatflash caused significant fire damage to Quartermaster items. The basic source of fires seemed to be gear of textile composition. Much baled and packaged clothing was completely burned at distances up to 2000 yards.

Baked and enamel type paints on Army equipment withstood heat much better than did the flat paint on ships.

This should be expected, since the former contain relatively small amounts of volatile matter.

It was significant that rubber tires and rubber materials suffered no serious damage. Rubber exposed in thin sheets such as cable coverings showed some effects of exposure to the high temperature.

(8) FIRES.

Only organic materials or materials containing volatile organic constituents broke into flames. Fires occurred on approximately 23 ships. Except on the INDEPENDENCE and SAKAWA, the fires were small and had no serious results. A serious fire occurred on the INDEPENDENCE in the badly damaged area aft of the hangar space and above the second deck. On the SAKAWA a serious fire in the after part of the ship burned from immediately after the burst, smoldering in the final stages, until the ship sank the following day.

There is evidence that many incipient fires within 1500 yards of the burst were extinguished by the air blast. Except for the fires and for effects on transparent substances, no significant increases in temperature occurred at a depth greater than a few thousandsths of an inch within any materials. Special maximum and minimum type thermometers directly exposed merely showed a temperature range within that of the usual daily variations. This is explained by the short duration of the intense radiation. Only thin, porous, or fibrous materials could come up to their combustion temperatures in the short time of illumination from the burst; fire or scorching resulted chiefly when such materials were protected from the wind by transparent covers.

Photographs showed clouds or vapors evaporated far ahead of the shock wave. These undoubtedly had their origin in organic materials such as greasy, painted, or lacquered surfaces and in other materials having volatile constituents. This evaporation formed explosive mixtures which could have been ignited by the radiation or detonated by the shock wave arriving within a few seconds after the light flash.

This probably gave rise to a sheet of flame which could have started fires. The high winds accompanying the shock wave no doubt extinguished some of the incipient fires. The high winds also forced these sheets of flame around complex contours which would account for the blistering, scorching, carbonization and soot deposits on surfaces not directly exposed to the burst.

Army Quartermaster exposed materials of a combustible nature suffered severely from fires throughout the array. Most of these were packaged in cardboard or light wooden boxes. It was reported in some instances that some fires had their inceptions from inside the cartons rather than from the outside. It was pointed out that combustible materials in boxes having metallic components generated fires, while packaged materials in the same location but with no metallic parts did not burn. Consequently some mechanism involving the metal parts may have contributed to the phenomenon. Such behavior is exceedingly difficult to interpret on known physical grounds and further experimental work is necessary to verify the reports and to determine the mechanism involved.

There was much discussion during the planning stage with regard to the possibility of large oil fires in the ships and on the water of the lagoon. A study of existing information from wartime experience indicated that such conditions were possible but were not likely to be serious. However, consideration of this factor had some influence on the placement of the ships in the array, so that in most cases vessels fully loaded with fuel were placed in the downwind semicircle. Fortunately no oil fires occurred, even in the case of heavily damaged vessels. Fuel oil is relatively difficult to ignite, requiring either atomization or the raising of temperature to a point where the volatile matter vaporizes rapidly enough to sustain combustion. The time duration of the heat radiation did not produce these conditions.

Swatches of different cloth materials were exposed on panels. Light colored cotton and woolen materials were generally least affected by the radiation. The variations observed may be attributed to the large proportion of ultra violet and infra red light from the ball of fire. Some materials such as rayon were affected more than others. Much analysis of the recorded observations remains to be done.

b. TEST BAKER

(1) GENERAL

The underwater burst produced severe underwater shock; air blast pressure; and water impact from fall-out from the column, from the base surge, and from surface gravity waves.

Underwater shock was the most significant cause of damage to underwater structure and of mechanical damage to most types of equipment. The order of shock to a vessel at 800 yards was about equivalent to that which would have been produced by detonating 300 pounds of TNT at 100 feet. The underwater physical damage of the second burst could have been approximated with a combination of torpedoes, mines and depth charges totalling not over ten tons of TNT.

The forces from air blast, falling water from the column, water impact from the base surge and the surface gravity waves had destructive effects on top side structure and equipment. It is difficult to separate the particular damage which resulted from each of these forces. The range of effectiveness of each may be roughly estimated, as follows:

(a) Air blast. The air blast from Test Baker corresponded to that produced by 4000 tons of TNT exploded in air. Heavy damage would be expected to 600 yards from such a blast.

(b) Fallout from column. The column probably contained less than 500,000 tons of water. Most of this was present as a suspension of fine drops in a hollow cylinder roughly 100 yards thick extending from 230 to 350 yards. The density of this suspension was about six times the density of air and the entire mass of water and air subsided at a terminal velocity of about 75 miles an hour, corresponding to the pressure produced by a wind of 150-200 miles an hour.

(c) Base surge. As the suspension of water and air fell out of the column, it billowed outward as the base surge. The base surge increased rapidly in volume and correspondingly decreased in density both through fall-out of water and through dilution with large quantities of air. Its velocity decreased linearly with increasing radius. At 550 yards, the density of the base surge was four times the density of air and its velocity was about 60 miles an hour. The dynamic pressure of the moving suspension was equivalent to that of a 120 mile an hour wind. At 700 yards, the density was less than 3 times the density of air and the pressure was equivalent to a 90 mile an hour wind. Beyond this range, little damage would be expected from the impact of the base surge. The base surge extended to 2,000 yards in an upwind direction, to about 3,000 yards crosswind and to more than 4,000 yards downwind. The suspended water continued falling out of the surge cloud for upward of 20 minutes. At 1,000 yards the fall-out amounted to about an inch of water. Throughout its entire extent, the base surge contained enormous quantities of radioactive material.

(d) Surface gravity waves. At 350 yards from the center, the height from the trough back of the first wave crest to the second crest was about 90 feet. This height decreased linearly with increasing radius. The second wave probably broke over the ships out to 600 yards, and because of its height and steep front, characteristic of a breaking wave, was capable of causing extensive damage. Much beyond 600 yards the waves ceased to break; the long wavelength and comparatively low height beyond this point resulted in a relatively gentle motion.

(e) Cauliflower cloud. Although the cauliflower cloud was impressive in appearance, it probably contained relatively little water compared to that in the base surge and it did not extend over as large an area in any direction.

(2) BUREAU OF SHIPS EQUIPMENT

(a) HULL

Topside structure and equipment were damaged to a distance of 800 yards from underwater shock, air blast, base surge and wave effects, and the impact of falling water. Damage to underwater structure and all types of equipment resulted from shock and accompanying excessive hydraulic loading, and high accelerations from wave effects. In general, except at very close ranges, the minimum range at which a vessel may be immune to disabling damage is determined not by structural considerations, but by the effects of shock on mechanical and electrical equipment. Underwater hulls stood up well, even in the cases of those vessels which were sunk. The involved topside structures on most target ships contributed seriously to radiological contamination and made decontamination more difficult.

Eight submarines were exposed for the test. Two, the SKATE and PARCHE, were on the surface. The remaining six were riding to moorings and submerged to depths between the surface and the bottom.

After the test, four of those originally submerged, the PILOTFISH, APOGON, SKIPJACK, and DENTUDA, had sunk to the bottom. The DENTUDA (about 1500 yards) sank due to minor leakage and was raised with little difficulty. The SKIPJACK (about 800 yards), raised after the test, sustained some structural hull damage. The PILOTFISH (about 350 yards) and APOGON (about 850 yards) were not raised after the test because of the damaged condition of the vessels and the obstacles of radioactivity on the floor of the lagoon and on the vessels themselves. The PILOTFISH suffered severe structural damage and flooding. The TUNA (about 1800 yards) and SEARAVEN (about 1400 yards) when raised from their submerged test positions were found to have negligible damage.

In the case of the surfaced submarines, the SKATE (about 900 yards) suffered moderate shock damage whereas the PARCHE (about 1650 yards) sustained no damage. But for the fact that the SKATE had a badly demolished superstructure from Test Able, it would have been possible to return her to the coast under her own power.

The effect of underwater shock was more serious and extended to greater distances at middle depths of the lagoon than near the surface, probably because of the longer duration of the shock pressures. This may explain, in part, the damage which was received by submerged submarines at greater distances than in the case of surface vessels. This subject requires further study.

(b) MACHINERY

Radiological considerations made it impracticable to conduct operating tests on most machinery units. Visual inspection of machinery units on the target ships indicated that machinery of current design will not be operable if exposed within a distance of about 800 yards from the origin of an underwater shock of this magnitude. Visual inspection did not reveal serious damage to machinery units between the ranges of 800 and 1400 yards; however, loosening and stretching of foundation bolts, and cracking of paint around the foundations indicated that severe stresses had been imposed. Inspection for operability might disclose internal machinery derangements. Such inspections will be conducted, as far as possible, on certain target vessels which are to be returned to shipyards for further examination. One boiler in the PENSACOLA gave evidence of having slight leaks after the test. This undoubtedly was caused by movement of the steam or water drums which disturbed the tube seatings in the drums. Radiological conditions prevented determination of the hydrostatic tightness of boilers. Piping systems were the machinery plant component most vulnerable to shock damage between 800 and 1400 yards, although no large scale failures occurred beyond 800 yards.

(c) ELECTRICAL

The principal damage to electrical equipment was the result of shock and flooding. Major shock damage occurred out to about 1000 yards. Moderate damage occurred to minor electrical equipment to a distance of about 1300 yards. Gyro compasses and similar delicate equipment generally were disabled within a distance of 900 yards. Diesel generators were in operation on twelve vessels, including the SARATOGA, and continued to operate until fuel was exhausted; the SARATOGA diesel stopped either as a result of fuel exhaustion or from flooding of the diesel compartment.

(d) ELECTRONICS

Shock damage was heavy out to about 1000 yards, and minor damage extended to approximately 1500 yards.

This consisted of widespread tube breakage, failure of mountings, and displacement of units.

Although there was some variation in the resistance of various equipment, and specific weaknesses in design were indicated, shock damage was fairly general to all types and varied only in magnitude. Equipment which had adequate shock mounting came through the tests with very light damage. Improvement of shock mounting methods for both complete units and contained components, to withstand the high accelerations experienced in atomic bomb explosions, appears capable of reasonable solution. This will prevent a major part of the damage to electronic equipment other than antennas.

## (3) BUREAU OF ORDNANCE EQUIPMENT

Heavy director foundations and pedestals suffered misalignment and shock damage inside 800 yards. Heavy equipment such as turrets had broken holding down clips, some damaged elevating screws, and the like. Eight inch mounts in the PENSACOLA at 750 yards were displaced from their seatings. The below decks plotting room in the HUGHES at 620 yards (the only one exposed) suffered damage to equipment. Below decks plotting rooms on most vessels inside 800 yards probably would have become inoperable. The decrease in damage with distance was marked as exemplified by comparison of the major damage to the HUGHES at 620 yards and the minor damage to the MAYRANT at 930 yards.

Ammunition stowages proved inadequate for the intensity of shock and heavy projectiles and powder tanks were torn loose from their stowage racks, indicating the need for improved stowage arrangements. Some powder tanks in the PENSACOLA were cracked, thereby setting up serious explosion hazards. However, after arrival at Kwajalein, ammunition in all vessels was removed successfully, under special handling precautions, without incident or casualty to personnel.

The operation of exposed ordnance installations on many target ships was impaired seriously as a result of procedures used in the process of radiological decontamination after the test.

## (4) BUREAU OF AERONAUTICS EQUIPMENT

Aircraft exposed topside either were blown or washed overboard, or completely demolished, out to 700 yards. Major to moderate damage extended to 1500 yards. Aircraft protected in intact below deck spaces remained essentially undamaged beyond 500 yards.

As with other equipment, radiological effects were most outstanding. They indicated the need for study in connection with the protection of aircraft from radioactive contamination and the development of decontamination procedures.

(5) BUREAU OF YARDS AND DOCKS EQUIPMENT

Except for the sinking of the YO-160, there was no apparent damage to BuDocks equipment, which consisted of three concrete floating structures and one steel pontoon. It is believed that the YO-160 was sunk by a combination of severe shock damage and swamping by the wave. The ARDC-13 capsized eleven days after the test as the result of slow leakage through a temporarily repaired crack in the shell which had been caused by Test Able. This target finally was sunk by a demolition charge.

(6) BUREAU OF SUPPLIES AND ACCOUNTS EQUIPMENT

No special displays were made for Test Baker. Foods in exposed locations were made unfit for use by radioactive contamination. Foods in closed compartments would be suspect in many cases inside 1000 yards.

(7) U.S. ARMY GROUND GROUP EQUIPMENT

Army equipment which was installed for the test generally was affected in a manner analogous to similar items of Navy equipment. It was comprised mostly of mechanical equipment remaining from Test Able. The pontoon bridge sections displayed at 1200 yards remained afloat.

(8) CONTAMINATION AND DECONTAMINATION

It became apparent on the afternoon of Baker Day, and more evident on Baker plus one, that except for five transports (APA's), general reboarding and inspection of the target vessels would be impossible under the conditions of radioactive contamination existing. Decontaminating the vessels by some means was the only possible solution to this situation. Consequently the Director of Ship Material began such work, and at the same time instituted experimental work with facilities available in an attempt to arrive at the best solution.

The first method which was attempted was the application of a vigorous wash down using sea water applied by salvage vessels from alongside. This procedure when initially applied had a marked beneficial effect although subsequent applications did not appear to produce significant results. It was necessary to wait for several days before giving this treatment due to the contamination existing in the surrounding lagoon water. It is regrettable that it was not possible to have attempted this operation before the materials had a chance to bake into the exposed surfaces of the ship. The next material which was tried was Foamite. It was available, has a slightly detergent action, and is a good marker serving to insure coverage. It had, however, only a slight beneficial effect.

Meanwhile a strong solution of boiler compound, lye and starch gave promise. Ten of the vessels of the Salvage Group (TU 1. 2. 7) were equipped hastily with tanks, piping and portable pumps. This solution then was sprayed over a ship and after a short drying period was hosed off. The target vessels were still so radioactive that the operations had to be carried on from a distance of about 50 feet, which made effective application difficult This procedure removed considerable paint and with it some of the fission products. The technique of application had a great bearing on the effectiveness of the process. It is believed that as the salvage vessels became more familiar with the process a fairly rapid and effective gross decontamination could have been accomplished.

As a result of this procedure it became possible to place relays of crews for periods of two to three hours on the NEW YORK, PENNSYLVANIA, PRINZ EUGEN, SALT LAKE CITY, CONNYNGHAM, MUGFORD, WILSON, and CARTERET. These crews proceeded with local decontamination under difficult conditions. Shortly after this stage was reached it was determined that hazards from alpha radiating particles existed, and were also present in the ship interiors. The evaluation of these hazards was impracticable with the facilities available in the field. Consequently, after conference with CJTF-1 on the existing situation, it was decided on 10 August to discontinue decontamination work by ships crews aboard.

Considerable reduction in radioactivity on these ships resulted from this work. This made it possible to conduct fairly good inspections on those vessels under less hazardous conditions.

It also made the necessary pumping-out operations on the NEW YORK, PENNSYLVANIA, NEVADA, SALT LAKE CITY, and HUGHES easier to accomplish. In the cases of those target vessels which had received some treatment, it made it possible to carry out at least limited inspection procedures and also made it a less hazardous operation to ready the vessels for the tow to Kwajalein. The FALLON which purposely had not been given decontamination treatment, and the PENSACOLA which had only slight decontamination treatment, presented most difficult problems in pumping out, inspection, making repairs to enable towing, and readying for tow, because of their high radioactivity levels.

## 5. MEDICAL ASPECTS OF TESTS ABLE AND BAKER.

This section is a summary report of the Naval Medical Research Section based on observations and findings to date. This section was compiled by the Officer-in-Charge of this group, Captain R. H. Draeger, (MC) U.S. Navy, and his Executive Officer, Captain Shields Warren (MC) USNR, who is now on inactive duty. The latter observed medical results of the two Japanese bursts.

### a. INTRODUCTION.

Operation Crossroads has provided a unique opportunity for the observation of radiation effects upon animals and other biological materials under comparatively controlled conditions. The data acquired at Hiroshima and Nagasaki give a general picture of the effects of an atomic bomb explosion upon a population mass. However, they are lacking in detail, particularly concerning the early stages of radiation sickness. The Japanese picture is complicated by malnutrition, disease, faulty vital statistics and disruption of medical service. The controlled conditions of the Bikini experiments have made it possible to establish clearly the important biological factors referable to the atomic bomb. These data will also be of value in the further interpretation of the Japanese studies.

The effects of gamma radiation must be considered in relation to the time over which the radiation is given on the one hand, and the amount of the body exposed on the other. If the radiation is restricted to a relatively small portion of the body, it is possible for an individual to survive several times the dose ordinarily fatal as total body radiation. It is also possible to give much more than a lethal dose of radiation, without noticable effect, if divided into small doses at sufficient time intervals. This latter principle is utilized in determining the so-called permissible or "tolerance" dose of radiation.

The tissues of the body vary widely in their sensitivity to radiation. The white blood cells, the blood forming tissue of the bone marrow, lymphoid tissue, and the reproductive organs are relatively sensitive. The cells lining the intestine and the hair follicles are moderately sensitive.

The nerves and the heart muscle are highly resistant. Heavy ionizing radiation may produce immediate death. Lesser amounts of radiation produce death in days, weeks or months often associated with intercurrent infection. Many months or years later, death may result from anemia, leukemia or cancer in those who survive. With doses of radiation sufficient to cause immediate death no specific tissue effect will be noted, but as the dose decreases, the tissue specificity of the effect becomes more and more apparent. In those who survive the initial radiation, vomiting, weakness, susceptibility to infection and diarrhea predominate at first. Later hemorrhagic tendencies, anemia and sterility develop. Some moderately irradiated survivors lose their hair. A few transiently sterile or still potent will have their sex cells so damaged that abnormalities in the offspring may result.

b. TEST ABLE.

Twenty-two target ships were chosen for the placement of animals in Test ABLE. The intensities of radiation received by the animals ranged from approximately 16,000 roentgen to negligible amounts. The exposure locations from the bomb center ranged from 630 yards on the USS INDEPENDENCE to over 5,500 yards on the LST 133. Animals were placed in representative positions on the ships ranging from the complete exposure of the signal halyards to the protection afforded by the steering engine room of a battleship.

The animals chosen: goats, pigs and rats were selected both for their ability to remain healthy in the tropics and for their sensitivity to radiation. Goats and pigs have a sensitivity closely comparable to that of man while rats are several times more resistant. A few guinea pigs, which are more sensitive than man, were included for comparative purposes. Mice having special susceptibility to cancer were also included.

A tabulation of the mortality statistics of the animals is given in Table I. These data, however, cannot be interpreted until correlated with radiation dosage which depends upon both distance and shielding. While this correlation has not been completed and detailed conclusions cannot be formulated at this time, certain general conclusions can be drawn.

Table I

Animal Mortality Statistics -Test ABLE.

| | No. exposed | Recovered Alive | Died Since Return | Killed for Study | Remaining Alive |
|---|---|---|---|---|---|
| Goats | 176 | 153 | 38 | 65 | 50 |
| Pigs | 147 | 136 | 32 | 88 | 16 |
| Rats | 3030 | 2500 | 729 | 962 | 809 |
| Mice | 109 | 108 | Returned to National Cancer Institute | | |
| Guinea Pigs | 57 | 55 | 55 | 0 | 0 |

Approximately 10 percent of the animals were dead upon recovery. The majority of these deaths were due to air blast. Some immediate radiation deaths occurred on the USS NEVADA at 700 yards. Undoubtedly there would have been immediate radiation deaths on the USS INDEPENDENCE at 630 yards had not fire destroyed many of the animals. Delayed deaths caused by radiation occurred out as far as the USS CATRON at 1750 yards. Significant radiation injury was found as far as 2500 yards.

The mortality ra e in rats exposed to air blast on the USS FALLON at 1300 yards was 60 percent and the USS PENNSYLVANIA at 1700 yards was 8 percent. No blast deaths occurred on the USS CATRON at 1750 yards.

Flashburns due to radiant heat produced few injuries in the animals because their hair afforded adequate protection against the brief exposure. Shaved animals covered by anti-flashburn cream were protected except for the control portion of their skin. Exposed skin of animals showed burns up to 3300 yards.

Neutron induced radioactivity within target ships did not constitute a serious hazard. Some activity in sodium and phosphorus containing substances was noted in locations where all personnel would have been killed by gamma rays.

The mice exposed at 2500 yards on the USS FILLMORE received much less (6 roentgen only) than the intended dosage of radiation due to the distance that the bomb exploded from the target ship. For this reason the genetic effects on the mice may be expected to be negative. However, they are of interest with respect to the possibility of development of mammary and ovarian tumors.

c. TEST BAKER.

The operating rooms of four APA's to windward of the bomb were chosen for the placement of animals in Test Baker to avoid exposure to the tons of water with which the ships were deluged. The intensity of radiation received by the animals ranged from approximately 2700 roentgen to 310 roentgen. These animals were first subjected to a relatively high dose of radiation during the brief time that the ships were enveloped in radioactive spray following the explosion. Subsequent to this they were subjected to continuous but decreasing radiation, due to the contamination of ships structure with radioactive material. A tabulation of the mortality statistics of the animals is given in Table 2.

Table 2

Animal Mortality Statistics - Test Baker

| Ship | Distance | Animals | Alive 30 July | Remaining Alive |
|---|---|---|---|---|
| USS GASCONADE | 716 | 10 pigs | 4 | 0 |
| | | 50 rats | 50 | 0 |
| USS BRISCOE | 950 | 50 rats | 47 | 14 |
| USS CATRON | 1326 | 10 pigs | 10 | 0 |
| | | 50 rats | 49 | 22 |
| USS BRACKEN | 1560 | 50 rats | 26 | 18 |

The deaths on the GASCONADE, BRISCOE and CATRON may be attributed to ionizing radiation. Since pigs and man have a similar susceptibility to radiation injury, it is significant that none of the pigs survived. Those deaths on the BRACKEN are probably due to destruction of water supply for some of the rat cages by shock.

No animals have shown any evidence of solid blast injury.

As was anticipated radioactive contamination of the target ships delayed recovery of the Test Baker animals some of which could not be removed for 5 days.

d. TENTATIVE CONCLUSIONS.

(1) Air blast injury is of importance only to exposed personnel within a radius of about 1700 yards. The 50 percent lethal point is around 1300 yards. At this point a lethal dose of gamma rays will also be received.

(2) Thermal radiation injury is restricted to exposed personnel and may be prevented by clothing or anti-flashburn ointment. Those burned in spite of this protection will also have received a fatal dose of gamma ray radiation. Tests of uniform materials demonstrated that white or light colored cotton or wool afforded the maximal anti-flash protection.

(3) Ionizing radiation constitutes the major hazard to personnel subjected to an atomic bomb air burst. All exposed personnel within 1200 yards may be expected to be rendered ineffective almost immediately and to die in a matter of hours or days. Between 1300 and 1500 yards they may be expected to be effective for a limited period of time and to die in a matter of days or weeks. A few within this zone will survive. From 1500 yards to 1900 yards minor or delayed symptoms will appear; some may die and some will recover without permanent damage. Beyond 2000 yards no significant radiation effects will appear.

(4) Ionizing radiation also constitutes the major hazard to personnel subject to shallow water atomic bomb burst. The radioactive material,which contaminated many of the target ships was conveyed by mist and spray. Ships beyond the range of the mist and spray were not dangerously contaminated. Since the area of contamination depends partly upon meteorological conditions, prediction of the range of biologic effects cannot be made with accuracy. In the problem of personnel exposure, cognizance must be given to the time interval between bomb detonation and the arrival of radioactive spray. This time may be sufficient for many exposed personnel to seek shelter.

(5) Physical data made available from other sections indicate that about 1.5 inches of steel are required to reduce the intensity of gamma rays one half, from which data the amount of shielding required to protect an individual at a given intensity may be calculated. The shielding effects of oil or water can also be calculated on the basis of their relative densities. About 15 inches of oil and 12 inches of water are required to reduce the intensity of gamma rays to one half.

(6) Within the effective range of neutrons, about 650 yards, many times the lethal dose of gamma rays will be received by unprotected personnel.

(7) Prompt and accurate estimation of the dosage of radiation received by each individual is of utmost importance. To this end the development of a dosimeter utilizing physiochemical principles is now underway as a result of work done at Bikini which indicates that such a device is feasible.

(8) Since the irradiation received by the animals produced death, serious illness and sterility, it may be concluded that the psychic effect of exposure to atomic bomb radiations may outweigh in importance all others with utter demoralization of even uninjured personnel.

End of preliminary summary
prepared by Officer in Charge
of Naval Medical Research
Section.

## 6. DISCUSSION OF EFFECTS ON PERSONNEL.

### a. GENERAL

Personnel exposed to an air burst will be affected by: air blast and secondary high velocity winds, and thermal, visible, and ionizing radiation.

An underwater explosion will produce casualties by the following forces: air blast and winds of lesser degree than in an air burst; solid blast (mechanical shock) resulting from underwater shock; heavy impact of water from a horizontal direction produced by the base surge and waves breaking over the ships; water impact from a vertical direction resulting from the water descending from the column; ionizing (nuclear) radiation for the duration of the mist or base surge, and water fall-out from the cloud; persistent radiation from the fission products deposited by the mist or base surge, water fall-out from the cloud, and waves.

### b. AIR BLAST AND SECONDARY HIGH VELOCITY WIND.

Air blast alone after an air burst will result in a heavy toll of casualties to exposed personnel out to about 1700 yards. The effect of the secondary high velocity winds will add to this toll both by its direct action on exposed personnel and the indirect action of loose and damaged equipment moved at high velocity by this force.

These two factors in an underwater burst are of much lesser order and are dwarfed by other forces affecting personnel.

### c. THERMAL RADIATIONS INCLUDING LIGHT.

These phenomena were significant only in Test Able. The effects extend to considerably greater ranges than do those of air blast and solid blast (mechanical shock) due to underwater shock. The blinding effect of the flash undoubtedly would immobilize exposed personnel at great distances for variable periods. However, it is probable that in a great many instances, personnel protected by even the lightest shielding would not be affected by these particular phenomena at ranges considerably less than those at which material will be immune to damage.

d. WATER IMPACT

The impact of water in both vertical and horizontal directions from the effects of the column fall-out, the base surge and the waves would cause many personnel casualties out to distances difficult to determine, but probably at least 800 yards. Casualties from radioactivity however will be greater than those from these causes.

e. RADIOACTIVITY

The effects of ionizing radiations on personnel are by far the most significant in both bursts. The ionizing radiation in an air burst consists principally of neutrons and gamma rays from the point source of burst. These, necessarily, are of extremely short duration. The neutrons have a range in air of about 650 yards while the gamma radiation extends in lethal doses to about 1400 yards. Adequate shielding to provide protection to personnel at ranges comparable to those at which material will be undamaged appears to be only remotely possible on any but the heaviest types of ships. There is no time to permit avoiding the effects of such radiation since it exists only for about 40 seconds. Fifty per cent of the total dose would be received within the first second, ninety per cent within the first ten seconds.

Radioactivity after the air burst was, generally, not persistent and did not require decontamination measures. Persistent radioactivity on the SAKAWA, SKATE, INDEPENDENCE, and YO 160 was fairly high, but reoccupancy of the vessels was not delayed more than the maximum of one week in the case of the YO 160. The concrete structure may have been partly responsible for this condition. In practically no case would persistent radioactivity be of operational importance under war conditions.

The radiations from an underwater burst are more varied and different in character. On a personnel incapacitating basis they are more serious. The neutrons are absorbed by the water and little if any gamma radiation is obtained directly from the burst. The resulting fission products, however, produce high level gamma and beta radiation. The target array becomes contaminated to a radius of from 1800 to more than 4000 yards, depending on wind conditions, by a combination of the radioactive mist of the base surge, and falling water from the cloud, and probably the upwardly projected column of water. Consequently, the radiations can be considered to emanate from all possible directions, such as all points of a sphere's surface, rather than from a point source. This situation remains during the period when the above phenomena are operative or until their individual subsidences occur. Exposed personnel, therefore, will be subjected to intense beta and gamma radiation during this period, the dominating factor being gamma radiation. It is to be pointed out that personnel would have periods of time varying from a few seconds to over a minute to evacuate to the more heavily shielded positions of the ship. This phase of radiation may be of lower intensity than that from an air burst but it is of longer duration. Therefore, the effects can be equally or more disastrous in personnel casualties to even greater distances than would result from the direct ionizing radiation from an air burst. Although shielding of any extent would lessen the effect of radiation, considerable thicknesses of steel are required to protect personnel completely against such radiation to distances as great as 4000 yards and more. The striking characteristic is that the average level of this radiation will be high out to the extreme range of the mist or the base surge, amplified by the influence of the falling radioactive water from the cloud.

There remains also persistent radiation emanating from fission products deposited on all exposed surfaces by the above enumerated phenomena. Exposed personnel would suffer acutely from this effect even though they were immediately decontaminated. Unexposed personnel who exposed themselves subsequently to radiation from contaminated surfaces also could suffer effects ranging from lethal to insignificant. Such exposure would be most difficult to avoid because of the general contamination of the ships structure by the fission products. Practically the only preventive step for saving personnel will be their immediate evacuation.

A further source of harmful effects on exposed personnel would be the ingress of fission products to closed spaces by way of ventilating systems. Such personnel would be subjected to the immediate effects from fission products and the longer term effects of inhalation of alpha emitters, or a combination of these. A cubic foot of the base surge contained a quantity of radioactive material which, if inhaled, and absorbed in the human system, would be many times a lethal dose.

The above discussion on radiological effects in both tests is necessarily general. Some of this information has been acquired from the Radiological Safety Section. It is included because of its close interlinkage with ship damage, ship operability, military efficiency and ship design. Firm and final conclusions as to the effect of radiation on personnel must be obtained from final studies of the Radiological Safety Group and the Naval Medical Research Section.

The following table which is an excerpt from the Technical Directors Preliminary Report, gives the summation of the radiation received at topside exposed locations on several ships after Test Baker:

DOSE IN ROENTGENS

| | Distance In Yards | Total Over a Long Period | 1st Minute | 2 Minute Cumulative | 5 Minute Cumulative |
|---|---|---|---|---|---|
| (1) UPWIND. | | | | | |
| (a) GASCONADE | 625 | 10,000 | 3180 | 5040 | 7050 |
| (b) PENNSYLVANIA | 1100 | 1850 | 90 | 520 | 1170 |
| (c) BRACKEN | 1425 | 1600 | 0 | 150 | 860 |

(2) CROSS WIND.

| | | | | | |
|---|---|---|---|---|---|
| (a) PENSACOLA | 640 | 10,000 | 2450 | 4400 | 6800 |
| (b) SALT LAKE CITY | 1125 | 2400 | 300 | 820 | 1500 |
| (c) CRITTENDEN | 1675 | 2900 | 0 | 510 | 1480 |

(3) DOWN WIND.

| | | | | | |
|---|---|---|---|---|---|
| (a) FALLON | 530 | 12,000 | 5420 | 7000 | 9200 |
| (b) YOG-83 | 1100 | 8000 | 840 | 2500 | 4850 |
| (c) WILSON | 1760 | 7600 | 0 | 600 | 3100 |

Calculations indicate that the total dose was approximately 50 percent direct radiation from the mist of the base surge and falling water from the cloud. Contaminated ships will be uninhabitable on a continuous basis for a long time to come, unless considerable time and effort are spent in removing the radioactive materials. Damage which was incurred during Test Able, in many instances, permitted the entry of water and contributed to the contamination of the interiors of the target ships.

7 DISCUSSION ON PROTECTION FROM RADIOLOGICAL CONTAMINATION AND RADIATION.

One of the most important results of the Operation Crossroads is the accumulation of information on radiation and on radioactive contamination. This information is valuable to both the military and civil establishments as a basis of study for national preparedness and national defense. It affects ships, but, to an even greater extent it also would affect harbors, shore establishments, industrial enterprises, and cities. Primary importance must be attached to the procedures necessary for the protection of personnel against neutron and gamma radiation and subsequent fission product radiation and contamination. It is conceivable that without these tests, either no steps or only relatively minor steps would have been taken to study the possibilities of protection against these phenomena. Prosecution of such studies with a high priority is an urgent matter. Coordination of effort will be required because of the numerous agencies involved, the complexity of the problem, and the limited number of qualified personnel available to make such studies. These should be made using all available data from previous bursts.

Operation Crossroads also provided a substantial field test of instruments presently available for the detection of radioactivity. Many defects and gaps in the capabilities of these instruments were brought to light. Continuing study and development in the field of instrumentation already is actively underway by the Bureau of Ships.

Action has been initiated in the Navy by Chief of Naval Operations directives coveling various aspects of radiological defense and protection. The Bureau of Ships has established a laboratory for the purpose of developing methods for the decontamination of naval vessels. The Bureau of Medicine and Surgery, Bureau of Aeronautics, and the Bureau of Yards and Docks are cooperating in this project. These studies will be applicable to other affected establishments. Steps are underway to coordinate this work between the military services and the Public Health Service.

Training programs already have been placed in effect to indoctrinate key personnel in the many aspects and conditions of the atomic bomb bursts. It is recommended that such training be expanded and continued on a permanent basis. Coordination of such training between the services also is a necessity. The ultimate should be complete indoctrination of both military and essential civilian personnel.

8. DISCUSSION ON CONTAMINATION OF SALT WATER SYSTEMS OF NON-TARGET VESSELS.

A secondary result of Test Baker was the radioactive contamination of all salt water apparatus in most of the non-target vessels which subsequently entered the lagoon. This occurred even though the seawater at the anchorages had only minute quantities of fission products present. Rust, scale of all types, and marine growths in salt water lines accumulated and held tightly these materials. Clearing up of these conditions on the return from Bikini became a major problem over which Director of Ship Material, acting also for the Bureau of Ships, was given cognizance. Methods and procedures of removal were de veloped by joint efforts of the Naval Shipyard, Hunter's Point, and Crocker Labratories, University of California. At this time, practically all non-target vessels have been given final radiological clearance.

The above circumstance was actually fortunate despite the many operational inconveniences which resulted. It focused attention on the necessity for protection against such contamination and also on the urgency of developing methods, materials, and procedures for decontamination. The Bureau of Ships and the Bureau of Medicine and Surgery have gained much valuable experience. The need for better instruments again was demonstrated as was also the need for better training of monitors. Facilities for continuing research and development along these lines have been established.

This condition also indicated the necessity for maintaining the cleanliness of all salt water systems and equipment. Numerous instances of pipe lines seriously obstructed with marine growths were noted. The methods developed for the decontamination of radioactive materials fortunately resutled in the removal of these obstructions. The need for periodic inspection and cleaning is indicated.

## III. GENERAL OBSERVATIONS ON PROBABLE USE OF THE ATOMIC BOMB

The atomic bomb is the most effective weapon which which has yet been devised for use in warfare. A single bomb is capable of effecting considerable damage as has been proved by use against land and sea targets. The damage which is inflicted by this weapon is of three types; mechanical damage to material and personnel, radiological injury of personnel, and psychological effects on personnel. The predominating feature of the atomic bomb is its insidious and devastating, anti-personnel threat; however, its mechanically destructive effects also are of high order.

It is inconceivable that another nation would seek war against this nation unless it had gained complete knowledge of the manufacture and use of this weapon. It must be assumed that an aggressor nation first would have in its possession a supply of atom bombs. At the same time such a nation would be prepared also to make the full use of its conventional weapons as well as any new developments. All of these would be aimed at creating the maximum effect on all features of the opposing nation's structure, - military, industrial and civil. This probably would be done as a prelude to war. A coordinated blow against berthing centers for inactive vessels of naval and merchant types conceivably might prove disastrous in itself.

## IV. RECOMMENDATIONS.

### A. DESIGN CONSIDERATIONS.

#### 1. GENERAL

Decisions as to the changes required in ship design and materials can be reached only after thorough and concurrent consideration of the many factors involved. Properly coordinated analysis and evaluation of the available scientific and technical data and of the other considerations, such as functional and operational requirements, is required in order to achieve the maximum benefits from these tests for design purposes.

No revolutionary or drastic changes in existing ship types currently appear to be indicated as dictated by the atomic bomb. Similarly no major corrections or changes in designs of existing ships seem necessary. However, many deficiencies which were revealed by the tests could be corrected with general profit by design changes or by the use of more suitable materials. It is certain that much can be accomplished at no cost in offensive characteristics. Refinements and improvements to the many and variegated aspects of ship structure, equipment, and materials should proceed with the aim of arriving at designs having uniformly greater resistance to all the effects of atomic bomb attacks with minimum increase in weight. This also will be of value in increasing resistance to attack by conventional weapons. Such refinements must be based on including all feasible protection against direct radiation and the persistent radiation resulting from contamination with fission products, as well as on the satisfaction of other military and structural requirements. Indicated structural improvements should not be overshadowed by the apparent impossibility of complete protection against radioactivity. However, changes which result in appreciable reduction of offensive characteristics should not be made solely to improve defense against the atomic bomb.

The general factors which must be considered are:

(1) The observed results of Tests Able and Baker, including:

(a) Physical damage to ships, equipment, and aircraft.

(b) Injuries to exposed animals, insofar as they are applicable to human beings.

(c) Established physical phenomena such as measured and calculated peak values and duration characteristics of pressure, wind velocity, temperature, shock, direct radiation, and persistent radiological contamination.

(d) Other effects such as those of the impact of falling water, large waves, and the base surge.

(2) Consideration of the calculated variations from the observed results of Tests Able and Baker which would result from changes in the height or depth of burst and in the efficiency of the bomb, and from improvements previously incorporated in newer designs of ships and material.

(3) Other military and operational requirements.

2. IMPROVED RESISTANCE TO DAMAGE OF NEWER EXISTING DESIGNS.

One of the objections which was raised to Operation Crossroads was that some of the target vessels were in many respects of older design and therefore were weaker in design and materials than more modern vessels. However, it was considered that it would be possible, on the basis of observed damage and of instrumentation data obtained, to evaluate what would have resulted to vessels of the latest design already built, or being built in each category.

The tests demonstrated the value of many recent improvements such as the following: heavier hull and superstructures; greater protection to topside personnel; heavier flight decks on carriers; increased watertight integrity; improved shock mounting of equipment; and higher strength double cased boilers.

## 3. GENERAL ANALYSIS AND CONCLUSIONS

a. Ship design has endeavoured to keep ahead of weapon design. The atomic bomb obviously is far ahead of ship design. It will be difficult, if not impossible, to design so as to retain reasonable military efficiency inside of certain limits which will be hard to define.

b. Generally speaking, evaluated design modifications arising out of these tests should be incorporated in new construction. It will be found desirable in some cases perhaps to make some modifications in present vessels, but it is not believed that considerable funds should be expended for this purpose. Improvements in machinery foundations of existing vessels, for instance, is not warranted. As regards equipment of improved design, it will be desirable to install this in present vessels when replacements become necessary.

c. Studies of damage sustained by different classes of naval vessels in all types of combat should be correlated with the damage received in these tests.

d. Review of the characteristics of combatant ship types is in order. The prospective applications of both present weapons and new types of weapons must be considered.

e. Vulnerability of exposed aircraft must be studied in connection with aircraft carrier operation.

f. A complete loss of power is intolerable. It studies indicate that invulnerability of the complete power plant cannot be obtained without loss of ships military characteristics, an attempt should be made to attain invulnerability, beyond the sinking range, of at least a portion of the plant. The answer well may be an increase of Diesel electric power for emergency and auxiliary use.

g. An overall analysis of systems, such as piping and electrical, should be made. Of particular interest are all types of pipe lines and their supports. Piping systems are vital to the operation of the ship. A wealth of information was obtained on this problem

h. A thorough study of all possible applications of automatic control equipment to all ship systems should be made. Automatic control equipment in emergency may be the means for retaining ship mobility after an attack in which extensive damage has been received.

i. A study is required of the perf rmance of all types of equipment both as regards the equipment itself and the methods of mounting and securing. For instance, ordnance equipment which is designed more specifically to withstand gun blast stood up better than exposed electronic equipment, not so designed.

It may be that certain equipment and components of equipment systems, such as electronics apparatus, cannot be designed so as to be invulnerable to atomic bomb attack within desirable distances. However, it should be possible to increase the present resistance of exposed radio and radar equipment to air blast and high wind pressures from studies of form, mounting, attachment, and new materials. Light weight aluminum castings must be improved or replaced with better shock resistant material. Consideration also must be given to the simplicity of spares which can be installed in a minimum of time with a minimum of labor. It is of equal importance that the stowage of such spares be such as to prevent damage.

j. The weight allocated to and the distribution of armor in present ship designs should be scrutinized. It is questionable whether the present weight and distribution is justified on the basis of actual experience during the recent war and of estimates of future trends in naval warfare and of probable atomic warfare.

k. The importance of watertight integrity in vessels was emphasized by these tests. It was known that this feature in the Japanese battleship NAGATO was poor for understandable reasons. The SARATOGA, PENSACOLA, HUGHES, SALT LAKE CITY, PENNSYLVANIA, NEW YORK, NEVADA, certain submarines, destroyers, and transports also exhibited weakness. The attainable maximum in watertight integrity certainly has not been reached. Despite the efforts which previously have been concentrated on this item, additional improvement on an exhaustive scale is indicated. Continual training of personnel in all aspects of the importance of maintaining watertight integrity is essential.

l. It is important to investigate the possibility of providing better protection for essential operating personnel against radioactive radiation. Personnel also must be trained to seek best available protection in cases of such attacks. This subject applies also to shore activities.

m. Detailed studies are required to determine the relative personnel casualties which will occur at various distances as a result of light, heat, blast pressure, wind effects, base surge, wave effect, solid blast incident to underwater shock and various radiation injuries, as well as psychological effects. Provision of all feasible protection will depend on these studies.

n. Detailed investigations should be made of the available shielding effect in various parts of existing vessels of different types. These studies will indicate the necessity for improvements in shielding. Even though complete shielding cannot be attained, shielding which will enable personnel to keep a vessel mobile for a limited period with the objective of saving the vessel for future operations must be considered.

o. Consideration should be given to the provision of [illegible] spaces for off-watch portions of the crew. Such spaces should [illegible] locations having maximum protection against radioactive rays. [illegible] increase the percentage of crew available for ship operation [illegible] attack. Thought also should be given to space within a ship [illegible] can take shelter with the maximum shielding protection.

p. Special towing and salvage arrangements for major types should be considered.

q. A number of target vessels - INDEPENDENCE, CRITTENDEN, GASCONADE, PENSACOLA, SALT LAKE CITY and HUGHES, are being returned to the West Coast for further detailed technical and radiological study, and for use in experimental decontamination work. This work is now in progress on the CRITTENDEN and GASCONADE.

These ships should be used also in conjunction with many of the detailed studies enumerated herein.

4. SUGGESTED IMPROVEMENTS IN DESIGN

Detailed design recommendations are beyond the scope of this report. Only the most obvious and important points are enumerated for consideration. Detailed recommendations will be found in the reports made by each of the groups of the Director of Ship Material. The extent to which these recommended steps are necessary and feasible should be determined from thorough studies which give consideration to all the factors involved. The suggested improvements do not contemplate violation of the principle that ship design must be dictated primarily by the functional requirements of the type. Requirements for protection against atomic bomb attacks must be determined and integrated into these functional requirements and also into the requirements for protection against other weapons and hazards.

a. Improvements in resistance to air blast, such as:

(1) Simplification of exposed areas of superstructure, at some sacrifice in present installations, and provision of higher average blast resistance in the remaining superstructure. Previous tenets of essentialities must be reviewed with the objective of downward revision. This must be coordinated with changes to reduce radiological hazards.

(2) Increasing blast resistance of stacks, uptakes, and boiler casings. This involves studies of form, mounting and materials.

(3) Investigation of design aspects peculiar to aircraft carriers such as increased strength of airplane elevators; improved design of flight decks and flight deck supports as compared with those of the INDEPENDENCE; and the improvement of blast protection for aircraft stowage spaces. Study of the practicability of closed hangar spaces is indicated.

(4) Increased strength of portions of weather decks in certain cases.

b. Improvements in resistance to shock, such as:

(1) The provision of more adequate resistance for prime mover components. This would require a comprehensive study of ship power plants. Shock effects on contiguous systems, such as piping services, and main propulsion units with their connected auxiliary services, indicated that failures in one part of any system could immobilize a large portion of the power plant. This reveals the necessity that a main reduction gear be able to withstand the same shock, as the associated turbines, main condensers, sections of line shafting and associated steam or other essential piping systems. The obvious answer is a determination of the optimun feasible acceleration against which all parts of the various systems should be designed. Machinery units should withstand shock loadings at least equal to those required to damage the hull structure.

(2) Careful design of foundations and attachments of comparatively heavy moving units such as turrets, gun mounts, directors, and radar installations. Replacement of machinery foundations and mountings in existing ships is not considered to be warranted. The improved mountings in latest vessels should be studied on the basis of damage received in these tests and instrumentation data obtained. Subsequent work should be based on the results of these studies.

(3) The provision of adequate shock mounting of electronic equipment and delicate ship control equipment such as gyro compasses.

(4) Sea openings in the hull must be considered on the same strength basis as the hull. Connected piping to the first sea valve should be in the same category. It appears quite likely that such piping failed in the SARATOGA and was an important factor in her rate of sinking.

c. Improvements in protection against radioactivity, such as:

(1) Provision of increased thicknesses of steel or other materials for shielding personnel in vital locations. This may involve

adjustment of existing weights which are devoted to protection against other forms of attack. Weights used to provide shielding from radioactivity must be effective against the permeating non-directional phenomena characteristic of the enveloping mist incident to an underwater burst as well as against the directional radiation incident to the burst.

(2) Increased integrity of the outer envelope of the ship to prevent entrance of fission products.

(3) Redesign of topside structure, even at the sacrifice of some present installations, to minimize the accumulation of fission products on the ship following an underwater explosion.

(4) Provision of air conditioning systems to permit crews to live for necessary protracted periods with the ship sealed up.

(5) Development of coatings which will resist contamination by radioactive materials. The glazed surfaces of high tension insulators for instance showed little or no contamination in areas where it is certain that the base surge and following wave produced conditions which resulted in contamination of paint, wood, and other materials. It was observed that abovewater paints exhibited highly retentive properties, while plastic type underwater paints did not. Since the two types of paint are used under different conditions, the principles of one may not apply to the other. This phenomena should be investigated.

(6) Provision for rapid decontamination of ships including, as possibilities, special sprinkler systems or improved location of water main risers, special decontaminating materials, decontamination spaces, special clothing for personnel doing the work, etc. Such decontamination procedures as are developed must not be destructive to essential installation and equipment.

(7) Development and design of equipment and installations which are resistant to decontamination materials and procedures. Such developments will improve reliability of the equipment and its resistance to deterioration under service conditions.

(8) Development of methods and apparatus for maintaining all parts of salt water systems continuously free from scales and marine growths.

(9) Development and supply of adequate instruments for detection of radioactivity on board ships and for the evaluation of radiation hazards.

## B. GENERAL NAVAL SCOPE.

Problems under numerous categories confront the naval service in connection with atomic warfare. Much consideration must be given to all aspects of the situation. In arriving at the specific actions necessary, the following points are presented:

1. Consideration of the strategical, tactical, and operation factors involved, such as:

a. Estimates of the probable damage to ships in standard formations at sea resulting from both air and underwater applications of the atom bomb.

b. The importance and practicability of wide dispersion of units under all conditions of operation.

c. Determination of the optimum evasion movements of ships before, during, and after attack.

d. The investigation of procedures and means to minimize the exposure of personnel.

e. The feasibility of providing fast transports to carry relief personnel from special personnel pools to the scene of an attack in order to replace those injured by radioactivity.

f. The provision of salvage vessels which have been modified to enable them to operate with greater safety in salvage and decontamination procedures. It appears desirable to have such vessels available at or near major ports, naval bases, and shipyards.

g. Determination of the relative probability of atom bomb attacks against ship formations at sea as compared with attacks against harbors, shipyards, and shore facilities.

h. Estimates of the effects, including radiological contamination, of attacks on harbors, bases, and shipyards, including also the effects on ships in such locations. Subsequent decisions must be reached concerning the dispersion of activities or of facilities within individual activities. One aspect of this problem is the necessity for providing underground facilities or surface facilities designed for protection against atomic bomb attacks.

i. Consideration must be given to concentrations of vessels in harbors and repair yards, both commercial and naval. This applies to both peace time and war time situations. One of the prime German errors in the last war was concentration of bombing on London. Had the same explosions been expended against merchant ship repair yards, where merchant shipping in the order of ten million tons was concentrated from month to month, British overseas shipping would have been crippled. A relatively weak naval power which had the requisite supply of atomic bombs, in this way could cripple the merchant marine and naval potential of a strong power in a series of coordinated attacks. Should such a national crippling be risked when it is considered that a relatively few atomic bombs might accomplish this objective as a prelude to war?

j. Coordinated studies of all the factors involved must be evaluated on a high level before definite recommendations can be made for any major modifications to be incorporated in new ship designs. Funds should not be allocated for drastic alterations to existing ships until this procedure is carried out. In the meantime, technical and scientific studies to further the improvement of such phases of ship construction and materials as obviously require treatment, should proceed. Many improvements are relatively inexpensive and should be accomplished regardless of the necessity for increasing resistance against atomic bomb attacks.

k. The principle of floating mobile repair and service units such as comprised Service Squadrons Seven and Ten during the war in the Pacific should be considered also for continental areas. This would give operating forces considerable flexibility during a critical peace time period when surprise attacks are likely. Their value subsequent to an attack on regular shipyards is apparent.

l. A significant point which must be evaluated is the present naval power of and the possibility of future acquisition of increased naval power by all potential enemies. This evaluation should be made on the basis of all recent naval warfare, prospective trends in future naval warfare, and the threat of atomic warfare.

m. The usefulness and effectiveness of all types of combatant vessels also should be evaluated on the basis of these considerations. The decision as to ratios of types of vessels in a modern naval fleet may be influenced by such an evaluation.

## C. NATIONAL SCOPE.

It would be regrettable, and might prove disastrous, if the work and funds expended in carrying out Operation Crossroads did not serve to focus attention on the necessity for making a comprehensive survey of all the implications on National Security and National Preparedness involved in Atomic Warfare.

Early realization of the benefits which should arise from these tests is dependent on supplying the necessary reports to the appropriate agencies for detailed study. It is believed that many reports or at least large portions of them can be declassified, so as to enable many groups to have access to those reports applicable to their work. Consequently it is recommended that all reports, including those of the Evaluation Boards be disseminated as soon as practicable; subsequently all reports should be reclassified to enable further distribution to personnel having need for them.

It is recommended that such investigations be conducted and procedures established as may be required to:

1. Correlate the observed results of Tests Able and Baker with all information obtained from the three previous bursts.

2. Extrapolate the observed results to obtain further knowledge of the most effective methods of using the atomic bomb against specific targets.

3. Determine the relative probability and effectiveness of atomic bomb attacks against ship formations at sea as compared with attacks against cities, large industrial facilities and harbors.

4. Determine methods of protection for such areas against all aspects of atomic bomb attacks.

5. Determine the necessity, extent, and feasibility of decentralization and dispersion of industrial and harbor facilities, and residential centers.

6. Establish satisfactory coordination of military and civil activities in all matters involving atomic warfare.

7. Maintain continuous Intelligence regarding potential application of atomic bomb attacks by other nations.

## D. RECOMMENDATIONS FOR CONTINUING STUDIES, INVESTIGATIONS AND ANALYSIS.

1. Operation Crossroads yielded much in the form of information and experience which will be of value in guiding and determining the conduct of experiments with conventional explosives against ships and structures. Such future experimental work should be conducted having the Bikini tests in mind so that results can be evaluated on the basis of atomic bomb attacks. Except for radioactivity effects, practically all the effects of the atomic bomb can be simulated by conventional explosives. Explosive tests against ships are considered a necessity to determine shock effects on large structure and heavy equipment, as there are no other practicable means of obtaining full scale shock effects. Modifications in shock mountings and other improvements should be installed for test purposes in target vessels which are to be used in any explosive program. It is recommended that such an explosive program should be prosecuted.

2. The results obtained from Operation Crossroads should be used for detailed technical studies. The problem has been discussed with the various Chiefs of Bureaus in the Navy, and as a result each Bureau is setting up a separate technical group to be responsible for future Crossroads work and for integration and coordination of this work between Bureaus. It will be necessary if this work is to proceed with fruitful results that the following be done:

a. The technical and scientific groups must be expanded as the needs require.

b. Separate and additional funds sufficient to carry out the work with reasonable speed should be provided.

c. The work involved can be considered as a new development and unforeseen, and therefore, allowances in personnel ceilings and funds must be adjusted to accomplish the work.

[redacted]

3. Observation of Tests Able and Baker, necessary liaison activities of the Director of Ship Material with all other groups and agencies, and study of the results of the tests emphasize the enormity of Operation Crossroads. The two tests were in effect seeds from which a harvest of technical and scientific results were obtained. Field observations in themselves provide only the foundation for a full realization of this harvest. Extensive and complex technical and scientific studies and much experimental work must be conducted before the tests can be evaluated completely. Coordination and evaluation of these studies, which involve many agencies, are necessary to attain the maximum results which can accrue to the Nation.

This evaluation must be conducted on a high level of design agencies, scientific consultants, medical authorities, strategical and tactical operational agencies, and intelligence agencies. Such a combined effort is required to establish any major design modifications, changes in materials, and to solve the vital problems concerning all aspects of protection against, and preparation for the possibilities of atomic warfare on both land and sea. The full implications of the atomic age on National Security, National Defense, and National Preparedness will not be realized unless this is done.

Finally, it appears that major decisions on design changes and modifications which involve military characteristics of vessels should be made on a high level by a group well informed on Operation Crossroads.

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Classification ~~(Cancelled)~~ (Changed to CONFIDENTIAL
By Authority of DASASC-3 memo: 29 Oct 56
By [illegible] Date 20 July 62

[redacted]

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Director
Defense Atomic Support Agency
Washington, D. C. 20301

CONFIDENTIAL

**Defense Special Weapons Agency**
6801 Telegraph Road
Alexandria, Virginia 22310-3398

TRC

10 April 1997

MEMORANDUM FOR DEFENSE TECHNICAL INFORMATION CENTER
ATTENTION: OMI/Mr. William Bush

SUBJECT: Declassification of Reports

The Defense Special Weapons Agency (formerly Defense Nuclear Agency) Security Office has reviewed and declassified the following reports:

| | | |
|---|---|---|
| AD-366718 | XRD-32-Volume 3 | |
| AD-366726 | XRD-12-Volume 2 | |
| AD-366703 | XRD-16-Volume 1 | |
| AD-366702 | XRD-14-Volume 2 | |
| AD-376819L | XRD-17-Volume 2 | |
| AD-366704 | XRD-18 | |
| AD-367451 | XRD-19-Volume 1 | |
| AD-366705 | XRD-20-Volume 2 | AD-366705 |
| AD-376028L | XRD-4 | |
| AD-366694 | XRD-1 | |
| AD-473912 | XRD-193 | |
| AD-473891 | XRD-171 | |
| AD-473899 | XRD-163 | |
| AD-473887 | XRD-166 | |
| AD-473888 | XRD-167 | |
| AD-473889 | XRD-168 | |

TRC 10 April 1997

SUBJECT: Declassification of Reports

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|---|---|
| AD-B197749 | XRD-174 |
| AD-473905 | XRD-182 |
| AD-366719 | XRD-33 Volume 4 |
| AD-366700 | XRD-10 |
| AD-366712 | XRD-25 Volume 1 |
| AD-376827L | XRD-75 |
| AD-366756 | XRD-73 |
| AD-366757 | XRD-74 |
| AD-366755 | XRD-72 |
| AD-366754 | XRD-71 |
| AD-366710 | XRD-23 Volume 1 |
| AD-366711 | XRD-24 Volume 2 |
| AD-366753 | XRD-70 |
| AD-366749 | XRD-66 |
| AD-366701 | XRD-11 |
| AD-366745 | XRD-62. |

All of the cited reports are now **approved for public release; distribution statement "A" applies.**

Ardith Jarrett

ARDITH JARRETT
Chief, Technical Resource Center

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