BOMBS AT BIKINI

Wed 7 Sept 88

Returned after 41 years

The good old days when
there was only one building

Allyn Vine

Please see that this book is returned to

Allyn Vine

WHOI

rm. 102

The towering wall of spray sweeps outward. Test B, July 25, 1946

Frontispiece

BOMBS AT BIKINI

The Official Report of Operation Crossroads

Prepared under the Direction of the
Commander of Joint Task Force One

by

W. A. Shurcliff

Historian of Joint Task Force One

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Preface

Tests A and B of Operation Crossroads, perhaps the most elaborate scientific tests ever conducted, are described in this official report with no attempt to prove or disprove anything. Its sole purpose is to present facts on the origin, planning, and execution of the joint enterprise.

The word *joint* needs emphasis. The Tests were neither Navy tests nor Army tests; this Report is neither a Navy report nor an Army report, and it has not been submitted to Army or Navy for approval. The Tests and the Report are the work of Joint Task Force One, an agency created by the Joint (Army and Navy) Chiefs of Staff and responsible only to them.

The Report does not attempt to duplicate the capable reporting of the many experienced reporters who witnessed the Tests. Through the press the general character of the Operation is known to hundreds of millions of persons here and abroad. The world knows that the first explosion was an atomic bomb detonation in the air on July 1, 1946, sinking 5 ships, and that the second explosion was an atomic bomb detonation underwater on July 25, 1946, sinking 9 ships.

But there is a wealth of information, much of it technical, which has not reached the public. Time was required to ferret out the significant facts; patience was required to piece them together; ingenuity was required to present the material without jeopardizing security. For reasons of security a few results have been omitted. These few are mainly technical correlations, as between exact distance and damage, or exact distance and pressure. Good public relations and the duty of the Services to the public demand that the fullest account possible be made available.

The facts included should help the public form sound conclusions and participate in the planning of national and international policies. Bulk release of energy from the nucleus is new on the earth; its portent is unlimited. But if it — and we — are to survive, it must be controlled. And adequate control cannot be achieved unless the people know the facts.

The present official account was written by the same group which prepared the over-all top-secret report recently transmitted by Vice Admiral W. H. P. Blandy, Commander of Joint Task Force One, to the Joint Chiefs of Staff.

To the many persons who helped in the preparation of this Report, I extend my thanks. I am particularly indebted to Mr. David Z. Beckler, Deputy Historian, and Mrs. Virginia Shapley, Editor.

W. A. Shurcliff,
Historian, Joint Task Force One

February 7, 1947

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Foreword

Operation Crossroads was directed by the United States for purposes of national defense; but its lesson has world-wide significance. The atomic bomb is definitely not "just another weapon"; its destructive power dwarfs all previous weapons. Observers at Bikini saw the bomb sink great steel warships and, with its penetrating nuclear radiations, reach into ships' interiors to kill test animals. The explosions in air and underwater were very different spectacles, but their end results mean the same: death and destruction on an enormous scale.

Only after the military implications of atomic energy have been grasped by the people of the world will the way be clear for working out effective international control. Throughout its ten-month tenure, Joint Task Force One attempted to give the world an intimate knowledge of the purposes, execution, and consequences of the Tests. The present volume not only summarizes much of the information already given out, but presents much material not previously disclosed. This volume, together with the recently published Pictorial Record, forms the final, and perhaps the most informative release on the Operation.

Vice Admiral W. H. P. Blandy, U.S.N.,
Commander, Joint Task Force One

1. WHY OPERATION CROSSROADS?

The gray-green dawn of July 25, 1946, enveloped Bikini Atoll. The target fleet lay still, with "Yoke" flags flying to signify all personnel had been evacuated. Like moving shadows the support vessels slowly filed out of the Lagoon. Last to leave was the flagship MT. McKINLEY. The Lagoon was deserted.

Just over the eastern horizon puffs of cumulus clouds appeared, heralding perfect weather for the final atomic test at Bikini. As the time for the explosion approached, men paced the decks, adjusted their binoculars, studied the deserted target fleet to fix in their minds the steel pattern soon to be shattered. Clearly visible was the doomed SARATOGA, floating majestically as she had throughout the war; among the forest of masts could be seen the tall thin mast of LSM-60, the ship from which the bomb was suspended. Close — fatally close — lay the mighty ARKANSAS.

Men stared fascinated as the relentless count began. In a few seconds the awful explosion would come. Not few: Two! One!

The results are history. Ships were crushed, and sank; two million tons of water and spray buried scores of ships.

Even more deeply buried — lost in the drama of the moment — were the underlying problems, the guiding motive. Why plan an Operation Crossroads? Why send 42,000 men, 242 ships, 156 airplanes, 4 television transmitters, 750 cameras, 5000 pressure gages, 25,000 radiation recorders, 204 goats, 200 pigs, 5000 rats and why transport Numbers 4 and 5 of the atomic bomb family thousands of miles across land and sea for two brief moments of majestic destruction?

The general answer is, of course, well known: It was imperative to find how to improve our Navy. As long as we have a Navy — and we will have one as long as the possibility of war remains — we want to have one of highest possible quality. We want ships which are tough, even when threatened by atomic bombs; we want to keep the ships afloat, propellers turning, guns firing; we want to protect the crews so that, if fighting is necessary, they can fight well today and return home unharmed tomorrow.

Underlying this general requirement is a long list of specific questions. If the list seems long, it is because of the unequalled importance of the atomic bomb. This new bomb is no mere creator of dazzling light and peach-colored clouds; it shakes the very foundations of military strategy. The questions are many; they are highly technical and eminently practical. They are not easily separated and cataloged. Years may be required to answer them, but answers must be found.

Naval architects, for example, were asking: When naval ships are caught by atomic bombs bursting in air what are the ships' "weakest links?" What parts fail? Where should added strength be provided? Do we need heavier side plating, or merely stronger joints? Which stands up best to the terrific stresses imposed by atomic bombs: riveted seams or welded seams? Does the ship's framework stand up? How about the decks, superstructures, and masts? What happens inside the ship, as to boilers and turbines? How about radio and radar? Are the guns damaged? Do fuel supplies escape and burst into flame? Is ammunition set off?

Important questions were asked about the ship's crew. Ship designers wondered how the crew would make out, whether men working below decks would escape unharmed, whether the blast wave or thermal radiation ("flash") or radioactivity would be most injurious. Most of all, they needed to know how to protect the men. Medical men wanted information as to how injuries can be diagnosed fastest and what medical treatments are best.

Naval tacticians were asking even more basic questions. How far must a ship be from an atomic bomb to survive? To prevent more than one ship in a fleet from being sunk by one bomb, how far apart must the ships be spaced? And if a bomb is about to explode, what avoiding action should the ship take? Should topside men remain at stations, or should most of them rush below for protection? How about harbors? Are ships particularly vulnerable there? How far apart should they be anchored to prevent one bomb from causing a large-scale "Pearl Harbor"?

Scientists and engineers were on the spot, too. They couldn't answer their own questions, and they were equally unable to answer the majority of the questions asked by ship designers. Just what does an atomic detonation consist of? What fraction of the tremendous energy release goes into the pressure wave? What fractions go into thermal radiation, gamma radiation and neutron radiation? Major question marks on pressure were: How great is the pressure? How fast does the pressure wave spread? At any one spot, how long does the high pressure last and what is the impulse exerted? How strong is the suction which instantly follows the pressure? Questions as to the inevitable and deadly gamma radiation were: At what range is it fatal? Are men behind steel walls protected? How thick must the walls be? When does the radiation sickness begin? Can the men continue to man their battle stations even after they have received fatal doses of the invisible radiation?

The effects of an underwater explosion were even more difficult to predict. Nobody knew how many millions of tons of water would be thrown into the air, how many miles this water would be thrown, what the shape of the water cloud would be, how big the water "crater" would be, or at what ranges ships might be broken or capsized by the first giant solitary wave expected to tower 100 ft. high from trough to crest.

Complete unknowns were such matters as: What percentage of the lethal fission products from the underwater explosion would remain trapped in the water? How badly would these insidious products contaminate the target ships? Would they seep inside the ships? How long would their deadly effect linger? What could be done to wash them away? Would an entire harbor be seriously affected?

If we could get answers to all these questions, then we could dare tackle the really big questions: Which is more serious, the explosion in air or the explosion underwater? What loss of military efficiency or general crippling of an actual fleet will result from an atomic bomb explosion? What new naval tactics are required? How should our shipbuilding program be modified? Are heavier ships now less valuable and lighter ships more valuable, or vice versa? Should we cut down our largest naval bases and make more of smaller size? In short, what must be done for our Navy to be of maximum use in the next ten or twenty years of the Nucleonics Age?

Some persons urged calling off the tests. They pointed to the high cost, expected to be many millions of dollars. They condemned sacrificing seaworthy ships. They feared tidal waves and chain-reactions in sea water. They thought cracks might be made in the earth's crust, allowing sea water to rush into the white-hot interior and form catastrophic quantities of steam. They feared antagonizing other countries. Some persons suspected that the target ships would be spaced too far apart, so that the tests would be ineffectual.

A few technical men said that the tests were unnecessary. They said that the atomic bomb had already been tested successfully at Alamogordo, New Mexico, at Hiroshima, and at Nagasaki. They had been told of the elaborate preparations made for the Alamogordo Test, of observers and scientific instruments that monitored the explosions over Japan. They knew of the careful inspections later made of the ruined Japanese cities and of the extensive studies of injuries suffered by the Japanese people. Some technical men said, in effect: "If we assemble the data already available, make additional small-scale tests required, call in our best theoretical physicists, then merely by computation we can arrive at the results we need; we don't need any further atomic bomb tests."

Technical men closest to the practical problems knew that no such makeshift would work. They knew that the Alamogordo test, although entirely successful as a demonstration, did not produce all the technical and scientific data needed. To be sure, the story obtained as to gamma radiation and neutron radiation was a good one. On the other hand the optical radiation data and pressure data were not as extensive as had been hoped; real gaps remained. And then, of course, no ships were involved.

At Hiroshima and Nagasaki a few photographs and pressure measurements were made of the explosions, but almost nothing of value to physicists was learned. Physicists wanted actual values of the following: pressure, impulse, accelerations, shock-wave velocity, ranges and intensities of gamma radiation, ranges and intensities of neutron radiation, decrease of the gamma radiation during the first few hours. And medical men, arriving on the scene late, found it difficult to tell what the early symptoms of the injured persons had been, and whether the injuries resulted primarily from flash burn, gamma radiation, or from secondary factors such as fires, and floods, lack of food, over-exertion, and lack of medical attention.

Nor could model tests give the physicists their answers. At least four serious obstacles stood in the way. First, you can't make a model atomic bomb; you have to use TNT. To imitate even a small "model" atomic bomb, you use an enormous pile of TNT, and the pile is so enormous that the whole test is spoiled, at least as far as close-in events are concerned.

Second, model making is not the simple matter it may appear to hobby-shop artists; a model ship, for example, has to be not only the same shape as the actual ship, but the model's sides and decks must be almost perfectly to scale also. This means that the sides of a model transport ship, for example, must be paper-thin, and at the same time must have the same flexibility, elasticity, and plastic flow as the steel plates on the transport ship. Model beams must be of paper-thin material also. Even the rivets must be closely imitated. The upshot is, of course, that no such thing as a really comparable model exists; the model will show damage from the model explosive charge, but nobody will know what the damage means in terms of damage to real ships. Determining the vulnerability of complicated equipment such as ships' boilers by means of models would, of course, be almost impossible.

Third, no one — not even the scientists in the Navy's Bureau of Ships or Bureau of Ordnance — knew how to fully interpret model studies of water waves, when the test to be imitated is the shallow-underwater explosion of 20,000 tons of TNT, or its modern equivalent, one atomic bomb. The crux of the difficulty is: the waves don't "scale" as other phenomena do. We can use a model fleet in a model lagoon, and we will be rewarded by obtaining a very fine model pressure wave. But the water waves will come out all wrong; they are much too high. They must be corrected by some rather uncertain calculation.

Fourth, we cannot imitate in a model test the sudden release of fission products and the sudden emission of neutrons.

Thus it appears to be a true paradox that to show what the smallest of bodies — the atom — can do in chain-reacting concert, we must use a testing ground many square miles in extent. In any smaller theatre, the atom's power cannot be displayed.

But this can be said: Once the full scale tests have been held, then the model makers and model testers come into their own; only then can they prove which types of models correspond to the real thing and which do not; they can tell with assurance how their model water waves are to be corrected to represent waves produced by the atomic bomb.

Anyone could have thought up the idea of testing the atomic bomb against naval vessels. It is indeed routine to test each new weapon in all major applications. The novelty of the proposed test of the atomic bomb against naval vessels would lie in the unprecedented scale and world-wide importance of the tests. These were the unique elements which challenged the imagination of scientist, officer, and layman alike.

The Los Alamos Laboratory, the group which has made all our atomic bombs, was probably the first to give serious consideration to "testing" the bomb against naval vessels. Even in 1944 Los Alamos scientists were looking into the possibilities of eventually atomic-bombing Japanese fleet concentrations. But Japan's navy was already doomed, and her ships were destined to avoid atomic destruction until July 1, 1946, at Bikini.

Immediately following President Truman's epoch-introducing statement of August 6, 1945, announcing the atomic bombing of Hiroshima, naval men and laymen began asking: "What would such a bomb do to a battleship? Or an entire fleet?"

Senator Brien McMahon (D., Conn.), soon to become chairman of the Senate's Special Committee on Atomic Energy, was quick to ask that the new bomb be tested against naval vessels. In a speech of August 25, 1945, he said, "In order to test the destructive powers of the atomic bomb against naval vessels, I would like to see these Japanese naval ships taken to sea and an atomic bomb dropped on them. The resulting explosion should prove to us just how effective the atomic bomb is when used against the giant naval ships. I can think of no better use for these Jap ships."

Lieutenant General B. M. Giles, in Tokyo headquarters, led off for the Army. On September 14, 1945, he proposed that at least two atomic bombs be used in the destruction of the Japanese Fleet. The proposal was radioed that same day by Major General C. E. LeMay to Washington, D. C., where it was weighed by Lieutenant General C. A. Spaatz and also by General H. H. Arnold, Commanding General of the Army Air Forces.

Only four days later, General Arnold put the matter up to the Joint Chiefs of Staff, the country's top military group.* He asked that the routine destruction of surviving Japanese vessels — recommended on Aug-

** The Joint Chiefs of Staff then consisted of: General H. H. Arnold, General G. C. Marshall, Admiral E. J. King, and Admiral W. D. Leahy.*

ust 28, 1945, by Admiral E. J. King, Commander-in-Chief of the U. S. Fleet and Chief of Naval Operations — be countermanded. He urged that a number of the Japanese vessels be made available to the Army Air Forces for use in tests involving atomic bombs and other weapons.

The Navy's response, made by Admiral King on October 16, 1945, called for broadening the proposal by having the Joint Chiefs of Staff control the tests and by having all pertinent groups of Army and Navy participate. Admiral King recommended that one bomb be detonated in the air and another in the water, and he made the very significant suggestion that a few of our own modern naval vessels be included in the target array.

To get detailed planning underway, General Arnold suggested on October 31, 1945, that the Joint Staff Planners, a permanent working committee of the Joint Chiefs of Staff, decide just what tests should be made and what groups should make them. The suggestion was accepted, and the Joint Staff Planners were asked on November 10, 1945, to proceed.

Their first act (November 13, 1945) was to appoint an "ad hoc subcommittee" to make a complete and detailed proposal. This Subcommittee, usually called the "LeMay Subcommittee," had the following membership — after three early changes:

Major General C. E. LeMay (Steering Member)
Brigadier General W. A. Borden

Colonel C. H. Bonesteel
Captain G. W. Anderson, Jr. (Navy)
Captain V. L. Pottle (Navy)
Commodore (now Rear Admiral) W. S. Parsons

The Subcommittee met frequently during the next six weeks, and thrashed out in full all the tests' principal features. The most controversial issues were: Who should command the prospective Joint Task Force? Should the target vessels carry full loads of fuel and ammunition?

Some of the Subcommittee members suggested that the Commander be chosen from Army officers having close familiarity with the Manhattan Project. Other members pointed out that the majority of the operation would involve principally the Navy: naval target vessels, naval supporting vessels, naval construction of shore facilities, inspecting and appraising damage to naval vessels. The final decision was made by the Joint Chiefs of Staff who designated Vice Admiral W. H. P. Blandy. Admiral Blandy, an ordnance specialist though a naval line officer, had been Chief of the Bureau of Ordnance from 1941 to 1943. He had commanded large Army and Navy forces of multiple types in Pacific amphibious operations in 1944 and 1945. Since November, 1945, he had been Deputy Chief of Naval Operations, Special Weapons, particularly charged with developing atomic energy devices and guided missiles.

Debate was long and vigorous on the question of fuel and ammunition loads. Air Forces' representatives initially proposed having nearly every target ship carry full loads of fuel and ammunition, to show the maximum damage the atomic bomb could do, including secondary effects of fires and ammunition explosions. Others opposed this proposal, pointing out that with the ships crowded abnormally close together, release and ignition of oil or gasoline from a single ship might set fire to all adjacent ships; the resulting damage might give an entirely false picture of what would happen to ships in their normal spacing. Such fires might destroy much of the really significant damage and large numbers of important scientific instruments too. (The satisfactory compromise reached is discussed in Chapter 7.)

The work of the LeMay Subcommittee culminated in a detailed plan submitted to the Joint Chiefs of Staff and accepted by them (with a few minor changes) on December 28, 1945.

Vice Admiral Blandy was soon ready with a detailed administrative and technical plan of action. The Joint Chiefs of Staff gave preliminary approval to the plan almost at once, and then referred it to the White House. The President studied it, and added "Approved Jan. 10, 1946. (signed) Harry S. Truman."

The next day, January 11, the Joint Chiefs of Staff designated Admiral Blandy Commander of Joint Task Force One, and directed him as follows:

1. By direction of the President, you are designated commander of a task force under the Joint Chiefs of Staff for the purpose of conducting tests for the determination of the effects of atomic explosives against naval vessels in order to appraise the strategic implications of atomic bombs including the results on naval design and tactics. You will organize a joint staff with adequate representation of land, sea, and air forces. You will include civilian scientists in your organization.

2. The general requirements of the test will be to determine the effects of atomic explosives against ships selected to give good representation of construction of modern naval and merchant vessels suitably disposed to give a gradation of damage from maximum to minimum. It is desired to include in the tests both air detonation and underwater detonation if the latter is considered feasible. Tests should be so arranged as to take advantage of opportunities to obtain the effects of atomic explosives against ground and air targets and to acquire scientific data of general value if this is practicable.

3. You are authorized to deal directly with agencies of the War and Navy Department in all matters relating to the preparation for the conduct of these tests; including direct access to the Manhattan District. Usual service lines will be available for administrative and logistic support of forces assigned. . . .

4. The Joint Chiefs of Staff will appoint as a separate agency, directly responsible to them, an evaluation board (committee) for the express purpose of evaluating the results of the tests. This board will be available to you for advice during the preparation of the tests. Appropriate sections of your organization will collaborate with this board as necessary, and you will provide it with all necessary facilities it may require to fulfill its functions.

5. You will prepare plans for the test including selection of a suitable site which will permit accomplishment of the test with acceptable risk and minimum hazard. Your plans for the operation and final report will be submitted to the Joint Chiefs of Staff for their approval.

For the Joint Chiefs of Staff:
/a/ A. J. McFarland
Brigadier General, U. S. A.
Secretary

Authority was now complete for holding the most observed, most photographed, most talked-of scientific test ever conducted.

2. EARLY PROBLEMS

Even before Joint Task Force One had been created, major problems were being tackled by the Army and Navy groups most interested.

Choice of site was one of the biggest problems. Any number of relatively near-at-hand sites in the Atlantic, the Caribbean, and the nearer parts of the Pacific satisfied many of the requirements, but none of these satisfied all of the requirements. What was needed was:

A protected anchorage at least six miles in diameter. (It must contain not only the enormous target fleet but also the even larger supporting fleet.)

A site which was uninhabited, or nearly so. (All inhabitants would have to be evacuated.)

A location at least 300 miles distant from the nearest city. (Radioactive materials released in the air might menace persons scores of miles to leeward.)

A location within 1000 miles of a B-29 base. (The airburst bomb was to be delivered by a B-29 bombing plane.)

Freedom from severe cold and violent storms.

Predictable winds directionally uniform at all altitudes from sea-level to 60,000 feet. (There must be no chance that the radioactive materials carried high into the air could be wafted back over the task force personnel by a fluke counter-wind.)

Predictable water currents of great lateral and vertical dispersion; fast currents avoiding important fishing areas, steamer lanes, inhabited shores. (Radioactive materials released in water must be dispersed reasonably rapidly, and without harm to persons or to the fishing industry.)

Control by the United States.

Bikini won out. Its 162 inhabitants could be transferred readily. The few coral heads obstructing the anchorage could be eliminated by dynamiting.

Bikini's location is shown in Figures 1 and 2. It is one of the 34 atolls making up the Marshall Islands group. Discovered in 1526 by a Spanish sea captain, the islands were rediscovered by the English Captains Gilbert and Marshall in 1788. Germany annexed them in 1885, and they were mandated to the Japanese after World War I. In World War II they were occupied by the Japanese.

Final choice of Bikini suffered one delay. Spokesmen for the fishing industry feared the explosions

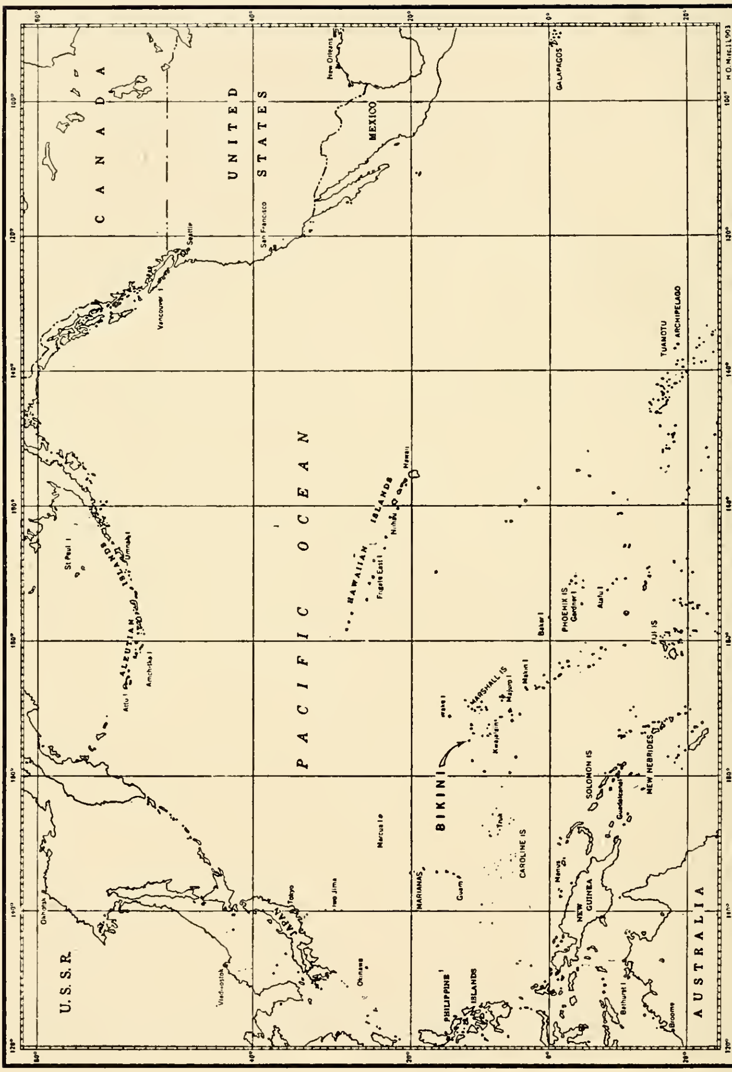


Fig. 1. Map of the Pacific, showing location of Bikini.

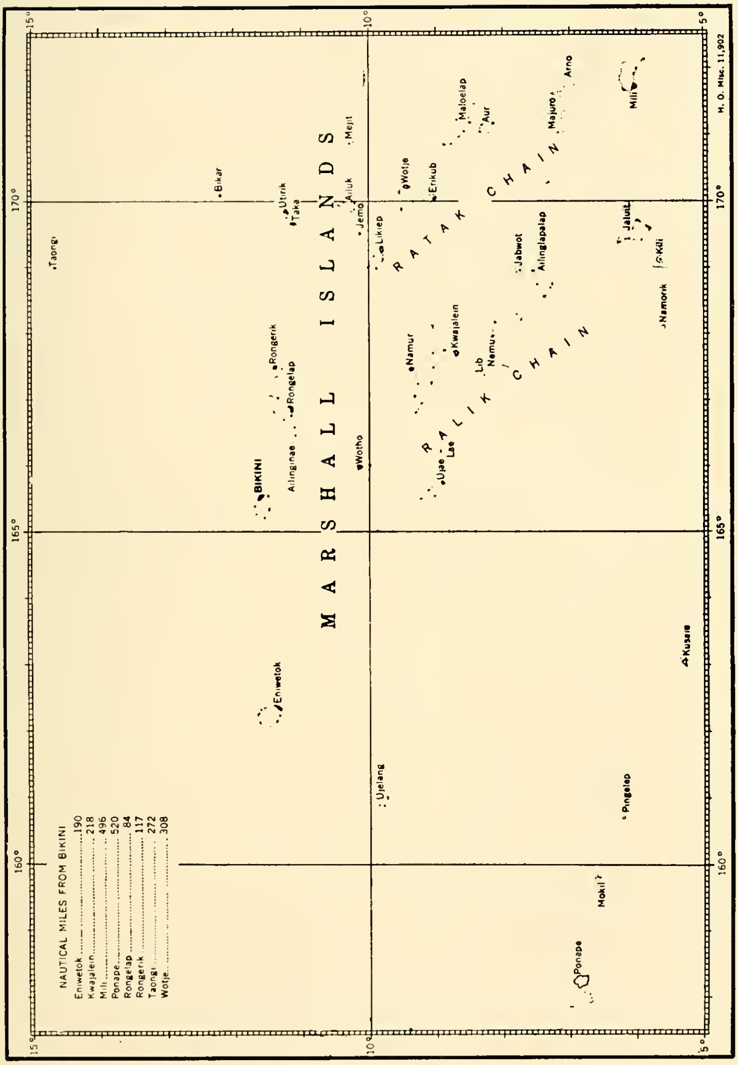


Fig. 2. The Marshall Islands, showing Bikini.

might kill millions of fish, even at great range. They feared also that whales or tuna fish might be abundant in the area, and might be killed, crippling various fishing activities in the Pacific. To evaluate any such dangers, advice was sought from the Fish and Wildlife Service of the U. S. Department of the Interior. The answer was definite: Bikini is so far from the migratory routes of whales at the time of year in question that no appreciable danger to whales exists; and the area is not critical for tuna fish or other fish of commercial importance. In particular, it is not a spawning ground for west coast tuna.

A real dilemma complicated the choice of dates for the atomic bomb tests. The reasons for holding the tests *soon* seemed very urgent; yet the need for delay seemed equally real. On the urgent side, these facts were clear: (1) The scientific resources of the Navy and Army (and the Army's Los Alamos Laboratory in particular) were declining from their wartime peaks; every month that passed left fewer scientists available to accomplish the highly technical mission lying ahead. (2) The supply of nontechnical service personnel, too, was diminishing; before long it would be difficult or impossible to obtain officers, technicians, or crews for the enormous fleet. (3) Civilian scientists to be "drafted" from universities were insistent on returning to their universities by early September; if they were to be used, the tests would have to be held in the spring. (4) Army and Navy budgets were expected to become continually smaller, and might easily be incapable of standing the expense. (5) Target vessels, particularly the obsolete vessels, could not be held available indefinitely. (6) Military and naval planners had to proceed with plans for future strategy and construction; the fundamental technical data were needed almost immediately.

But technical and nontechnical men alike saw the other side. They saw that a suitable task force could not be assembled overnight, that much paperwork must be done before men could step forward to plan and execute the operation capably. They realized that readying the ships of the great target fleet would be an enormous job; months would be required even if many different shipyards cooperated in the work. They knew that a multitude of scientific instruments of entirely new types must be designed, built, tested, installed. They knew that careful rehearsals of all technical and operational phases would be required before anything like full value could be got from the Tests.

After consulting all his deputies and advisers, Admiral Blandy named May 15, 1946, as date for the first Test, the explosion in air; the second Test, the explosion beneath the surface of the lagoon, was to occur approximately six weeks later. The race against time was started.

No one knows whether the race would have been won or lost. For on March 22 a delay was ordered; the President directed that the Tests be postponed approximately six weeks in order that Congressional observers could complete their legislative work and yet see the Tests. July 1, then, became the new target date.*

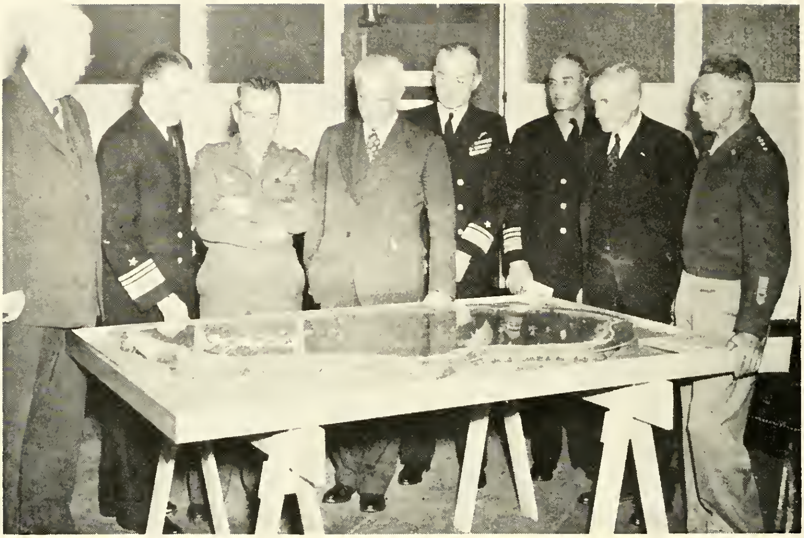
What was the best altitude for Test A, the explosion in air? This question shuttled back and forth across conference tables for months. Scientists at Los Alamos and in Washington swapped arguments as to what altitude would produce sinkings at the greatest radius or what altitude would produce moderate damage at greatest radius. Clearly a low altitude would better insure sinking the nearest ships; but a greater altitude would permit the blast wave to reach out farther and do at least moderate damage at greater radius. While these scientists were matching formulas and graphs in friendly tussle to arrive at the best choice of altitude, they were also re-studying the results of the Alamogordo, Hiroshima, and Nagasaki explosions.

* *One of the most unexpected results of the postponement was the opportunity it gave to the Task Force's Wave Motion Section to take the measure of the great* tsunami *("tidal wave") which struck the Hawaiian Islands on April 1, 1946. When the postponement was announced, the wave motion experts were en route to Bikini; accordingly, they were directed to go to Pearl Harbor to await further instructions. They had no warning there of the approach of the* tsunami, *and did not get their 65 tons of wave measuring equipment into action. But they went to work quickly inspecting the inundated areas and piecing together all available evidence. A full report on the* tsunami *was issued later, and some of the information learned was put to use in perfecting plans for measuring bomb-produced waves at Bikini. Mr. N. J. Holter, head of the Section, was asked to assure the population by radio that no such danger threatened in the forthcoming atomic bomb explosion.*

A mock-up of the air operation planned for Test A is studied by Vice Admiral W. H. P. Blandy, Commander of JTF-1, and Maj. General W. E. Kepner, Deputy Task Force Commander for Aviation (both standing) and Brig. General T. W. Power (kneeling). The Air Plan specified the positions and courses of all Army and Navy planes, manned and unmanned.

A Washington press conference question is answered by Rear Admiral W. S. Parsons, Deputy Task Force Commander for Technical Direction. Flanking Admiral Parsons are Rear Admiral T. A. Solberg, Director of Ship Material, and Dr. R. A. Sawyer, Technical Director. On the table is a model of Bikini Atoll.

Plate I



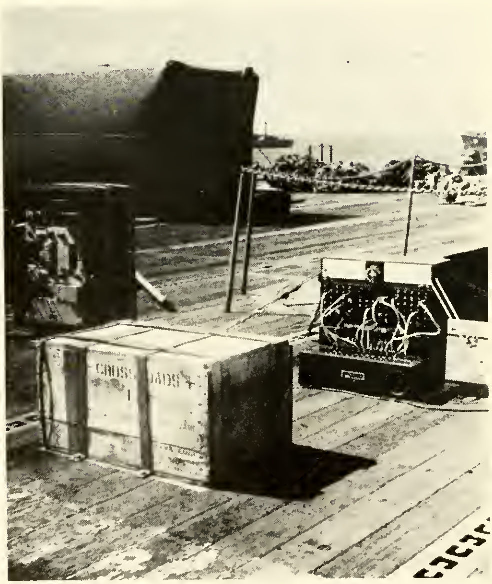
UPPER. Adm. Blandy (left) confers with the Joint Chiefs of Staff's Evaluation Board. Left to right are Lt. Gen. L. H. Brereton, Dr. K. T. Compton (Chairman), R. Adm. R. A. Ofstie, Vice Adm. J. H. Hoover, Maj. Gen. T. F. Farrell, and the late Gen. J. W. Stillwell. LOWER. Activity in Bikini Lagoon.

Plate 2

Steel towers were erected on several islands fringing the lagoon to house automatic cameras and other instruments. Cameras are installed inside lead-walled vaults whose doors are arranged to close automatically after the filming has been accomplished, thus protecting the film from gamma radiation.

Native outrigger sailboats are of double-ender type; they can beat to windward without coming about. Thanks to their speed and stability, they are used even for hundred-mile trips across open ocean, from atoll to atoll. These boats, together with their native owners, were evacuated aboard LST 1108 to Rongerik, another of the Marshall islands.

The two supporting carriers, SAIDOR and SHANGRI-LA, were used for launching Navy drone and drone mother planes, photographic planes, and helicopters; also for processing photographs. Navy drones were landed on Roi island. Only one accident occurred in the course of their operation. The carriers bore small forests of radio and radar antennas.



On the only clear platforms available — ships' decks—nearly every kind of Army material was placed for exposure to the A-Day explosion. This exposure program, which was directed by Colonel J. D. Frederick of the Army Ground Group, included everything from machine guns, flame throwers, and radio sets to clothing, canned goods, medical supplies, and skiis. Crated equipment was secured to the deck by means of steel straps and bolts. The information gained filled seven volumes.

Plate 4

Surrounded by collecting bags, bottles, knapsacks, and other paraphernalia cherished by naturalists, Dr. J. P. E. Morrison, Assistant Curator of Mollusks at the U.S. National Museum, examines a seafaring bird caught at Bikini. Careful censuses were made, both before and after the explosions, of principal types of animal and plant life.

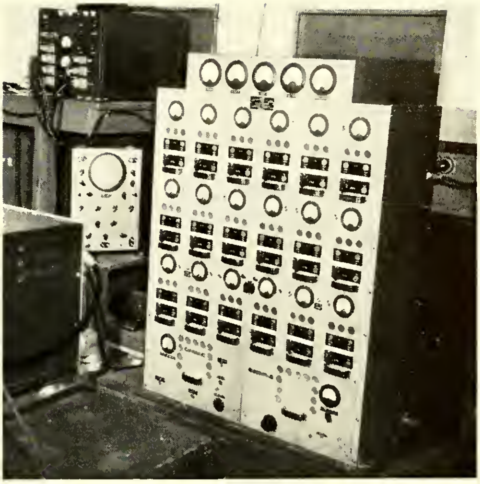
Sonobuoys to be used in the two Tests are inspected before being moored in assigned positions in the target area. The column mounted above the buoyancy barrel carries a horizontal, eight-sided loop serving as artificial electrical ground. Above this may be seen the small vertical antenna.

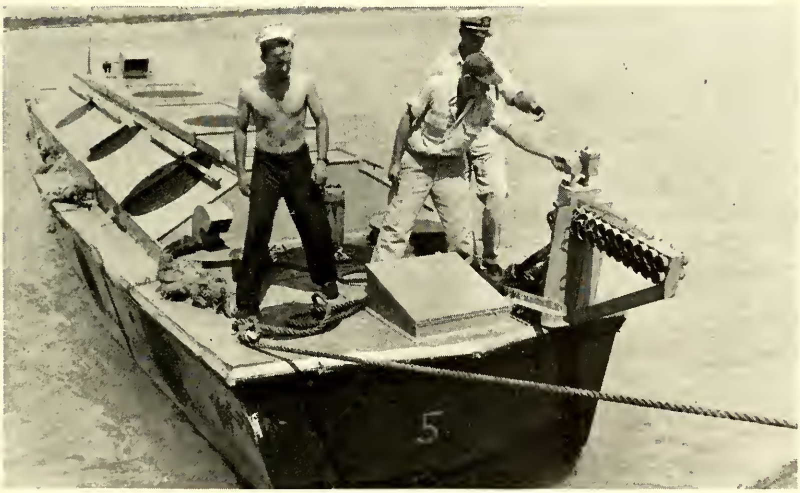
Plate 5

An experimental wing panel is mounted by the Army Ground Group on the deck of a target ship, to find the vulnerability of such panels to atomic bomb explosions. Visible along the deck are a tail fin, a stabilizer, and a range-finder. All items are clearly labeled for post-explosion identification.

Plate 6

This Navy-NDRC radio telemeter receiving equipment permits scientists miles away to follow the performance of unmanned planes flying through the explosion area. Eighteen amplifier channels decode and magnify the information radioed automatically from the drone planes. Permanent records are provided by the oscillograph, shown at the rear.





Radio-controlled drone boats were used to traverse the target area after each test, take samples of lagoon water, and send back information as to extent of radioactivity encountered. Smoke signal equipment may be seen overhanging the stern. The boats were guided by transmitters aboard the BEGOR.

Plate 7

Goats, pigs, guinea pigs, and rats were exposed on many ships in Test A to show what effects would be produced by the shock wave, visible radiation, thermal radiation, and nuclear radiations. The animals were given sufficient food and water to last ten days. Only pigs and rats were used in Test B.

Plate 8

The outcome: occasional major changes of mind, and new line-ups of those favoring greater or lesser altitude.

Meanwhile the operational men were talking *feasibility*. If it were much more convenient and accurate to set off the bomb atop a cheap tower, then that would be an argument for choosing an altitude you could reach with such a tower. Some thought was given to use of a tower, possibly on a headland if greater altitude was desired. Little thought was given to placing the bomb atop the mast of a battleship since this would probably mean sure and almost meaningless loss of the battleship, and in any case this would definitely limit the altitude to about 100 feet. The feasibility of suspending the bomb from a captive balloon was explored and rejected, since officers familiar with the erratic behavior of such balloons argued strongly against any such plan.

Other forces also were at work to influence the choice of altitude. Some persons pointed out that a rather low altitude would make Test A rather similar to Test B in which the bomb was to be detonated at or just below the surface. Air Forces' spokesmen pointed out that dropping the bomb from an airplane would not only provide invaluable experience in precision atomic bombing but would also remove all restrictions on altitude of the explosion, permitting the bomb to be dropped from an optimum altitude.

After all groups had given their views in full, the decision was made. It was based principally on the criterion of producing serious damage at greatest possible range. While the exact altitude chosen is restricted information, it may be said that the altitude was several hundred feet.

For Test B, the underwater explosion, the problem was debated even longer. Many pages would be required to trace the arguments and counter-arguments for setting off the bomb a few feet above the surface, exactly at the surface, a few feet below the surface, or considerably below the surface.

Some of the most interesting arguments were these: If the bomb were detonated just above the surface of the water, energy transfer to the water would be poor, most of the fission products would go upward in the mushroom, and, in general, the test would differ very little from Test A. Even if the bomb were detonated at the surface or very slightly beneath the surface, no really impressive underwater pressures would result, and again the test would not be far different from Test A. In fact a detonation very slightly beneath the surface of the water might be especially *ineffective;* neither the air pressure wave nor the water pressure wave would be maximized, and it is possible that a curtain of spray might be thrown up which would actually screen off a large part of the pressure wave in air and nearly all the thermal radiation, gamma radiation, and neutron radiation.

The greater depth for Test B appealed to nearly everyone except the engineers who would have the job of placing the bomb at the specified depth and detonating it there. Atomic bombs are new; none had ever been set off beneath the surface of the water. In attempting such an unprecedented act, it would be necessary to provide means of "keeping in communication" with the bomb at all times, not only to fire it (or, in an emergency, to *prevent* its firing) but also to test it. Unique security problems were presented too, since for a short interval the bomb would be very close to thousands of persons not authorized to see it.

So difficult was the decision as to the best depth of the bomb, that for a long time two alternative plans were carried forward side by side. Not until late in the winter was the final decision made: that the bomb was to be suspended at appreciable depth — beneath an "expendable" ship.

No one should think that these problems arose at expected times in well-crystallized form. They appeared unexpectedly; they had a habit of being almost inextricably tied up with other unanswered questions. Many of them arose even before the creation of Joint Task Force One on January 11, 1946, before clear lines of authority were established, before a firm directive had been issued as to the principal purposes of the Tests. And the key persons concerned were usually scattered across the country. A question raised by a scientist at Los Alamos, New Mexico, might be sent by coded telegram to the Manhattan Engineer District's office in the New War Department Building, in Washington, D. C.; here the question would be decoded — perhaps in somewhat puzzling form — and forwarded, say, to representatives of the Chief of Naval Operations in the Navy Building. Here a definite reply might be delayed until a civilian adviser located at Princeton, N. J., had been consulted. By the time the Princeton expert had been brought to Washington, some of the Washington men might have been called to Roswell Field, New Mexico, where the B-29's were being readied. By the time the answer was ready, the spotlight of interest might have shifted; a whole new set of questions might have taken the center of the stage.

Thanks to cooperative spirit, the telephone, the airplane, and high priorities, the problems were solved. The way was cleared for detailed planning.

3. PLANS AND PLANNERS

Joint Task Force One began its ten-month lease on life on January 11, 1946. It had no time for leisurely growth. Administrators had to be appointed immediately. Tentative plans had to be formulated at once and approved within a few days.

The growing infant had full backing. The Secretaries of War and Navy immediately issued orders to give the Operation full support. Officers, enlisted men, scientists, and technicians, were made available as required. Laboratory facilities were granted freely. Quarters were offered, as well as supply lines, funds, and equipment. Nearly every Service bureau, branch, and division shared in the effort. Thanks to highest priorities, the Task Force grew rapidly and smoothly.

Meanwhile, Admiral Blandy was conjuring a name. "Crossroads" seemed good, but it was a word already in use in certain code work. The code people were consulted, and agreed to surrender the name. So, on January 12, 1946, the Operation was christened "Operation Crossroads."

Admiral Blandy drafted the Task Force organization, and quickly assembled a central staff. He chose experienced officers from Army and Navy for the top command and staff positions; the men were chosen for their ability to act promptly and skillfully, without extensive instruction or deliberation.

Rear Admiral W. S. Parsons was chosen to direct the technical and scientific work. He was given the title of Deputy Task Force Commander for Technical Direction. His responsibility extended to preparing the ships, instruments, and test animals, detonating the atomic bombs, and determining the results of the explosions. Although he played a central role in the planning, even before the creation of the LeMay Subcommittee of which he became a member, his designation as a Deputy Task Force Commander of Joint Task Force One was not actually formalized until February 26, 1946.

Atomic bombs were not new to Admiral Parsons. For over two years he had served at the Los Alamos Laboratory, where he was head of the Ordnance Division. And he had flown in the *Enola Gay* on her historic flight to Hiroshima; he not only supervised the combat delivery of the Hiroshima bomb but personally assembled the bomb after the takeoff. His familiarity with the bombs and with Manhattan Project officials made it logical that he should be principal intermediary between Joint Task Force One and the head office of the Manhattan Project. Admiral Parsons' large and versatile technical organization is described in detail in a later chapter.

To direct the extensive air activities of the Operation, Major General W. E. Kepner of the Army Air Forces was brought in. His broad experience included service in the Marine Corps and Army Infantry in World War I, participation in the development of the use of lighter-than-air craft at Lakehurst, N. J., and several important Army Air Forces commands in World War II. As Deputy Task Force Commander for Aviation, General Kepner's responsibility extended to Navy air operations as well as Army air operations. It included planning, organizing, and directing the operations. The many novel problems he faced are described in a later chapter.

When it became clear that the Army Ground Forces also had a stake in the Tests, a Ground Forces' Adviser was designated: Major General A. C. McAuliffe. His duty was to advise the Task Force Commander on the planning, organizing, and execution of the Ground Forces' program, including exposure of a wide variety of Army equipment to the explosions.

To handle the enormous quantity of problems arising as to personnel, public relations, military security, ship movements, communications, and supply, a Joint Task Force operational and administrative staff was assembled under Commodore J. A. Snackenberg, Chief of Staff. Of his four principal assistants, two were drawn from Army and two from Navy. They were: Captain Robert Brodie, Jr. (Navy), Assistant Chief of Staff for Personnel; Brigadier General (now

Colonel) T. J. Betts, Assistant Chief of Staff for Intelligence; Captain C. H. Lyman (Navy), Assistant Chief of Staff for Operations; and Brigadier General (now Colonel) D. H. Blakelock, Assistant Chief of Staff for Logistics. To handle the innumerable problems which would inevitably arise in Washington, D. C., after the Task Force had left for Bikini, a special rear echelon group was created under the command of Rear Admiral F. J. Lowry.

The relationship of positions of Commander, Deputy Task Force Commanders, Chief of Staff, and Assistant Chiefs of Staff is shown in Appendix I.

Before discussing the technical phases of the Operation, we shall describe the less glamorous but equally important problems encountered by Commodore Snackenberg and his assistants.

PERSONNEL PROBLEMS

Handling of personnel matters was a long and uphill struggle. Personnel had to be recruited just when the majority of Service men were heading for the exit from military life. The trend had to be combated. Pleas were made to many officers and enlisted men on the point of returning to civilian life; special TAD's (orders for temporary additional duty) were drafted; promises were made that the men would be released immediately on completion of the Operation. In the Navy, which was to supply over 90 per cent of the personnel, the Bureau of Naval Personnel put its weight behind the drive. The Bureau of Ships, Bureau of Ordnance, Bureau of Aeronautics, and several other bureaus also dug deep for personnel. And the same cooperation was given by the Army.

Mere numbers were not enough. It was specialists that were particularly needed. Especially hard to find were electricians, radio and radar men, oceanographers, bomb disposal experts, veterinarians, experts on fish and blood.

Particularly acute was the dearth of radiological safety men. During the re-entry stages after the explosions, many lives might depend on the availability of men who could quickly and reliably detect dangerous concentrations of radioactive materials on target ships, or in lagoon water. Such men, called monitors, were also needed to clear the way for the speedy removal of animals and apparatus from the exposed ships. Similarly, they were vital to the quick saving of target ships which might be on the verge of sinking. Several hundred recruits were selected and trained, but when the tests were postponed by the President, many resigned. More were recruited; they were given last-minute training before departing for Bikini and while at sea. Over 225 monitors were actually available in the crucial periods at Bikini; and although they were spread thin and worked long hours, they performed their tasks excellently. They have the honor of being charter members in a new branch of defense: radiological safety.

The demand for photographers, too, far exceeded the supply. First, the Services were combed; then appeals were sent out to hundreds of ex-servicemen who had been trained in military photography during the war. Over one hundred responded.

But corralling the men was only a part of the problem. They had to be inoculated against diseases common in the Pacific Theatre. They had to be assigned living and working space, fed, and transported. Recreation areas had to be provided on Bikini Atoll and elsewhere. Finally, problems as to their return, replacement, and release had to be faced.

Hiring of civilians was especially complicated also. Special contracts and payroll procedures had to be improvised almost overnight. Some men were arbitrarily placed on the Los Alamos Laboratory payroll; others were paid from funds in the Office of the Secretary of the Navy. Nearly every Service department concerned with the handling of personnel groaned under the load of unprecedented problems demanding immediate answers.*

Despite their unending problems, Captain Robert Brodie and his assistants worked along doggedly, and each time a ship headed out for Bikini, an effective

* *E.g. before the author could obtain a civilian secretary, formal authority had to be obtained from the Joint Chiefs of Staff.*

crew was aboard; each time a group of experts was needed to solve some unexpected technical problem, the experts were there.

INTELLIGENCE FUNCTIONS

Brigadier General T. J. Betts, Assistant Chief of Staff for Intelligence, had a positive and negative function. The negative job was maintaining military security. Never before had a nation fanfared its most secret military weapon so closely before the eyes of the world. Never before had an atomic bomb been detonated in front of the world press. Each man participating was checked for character and loyalty.* Special pass cards were issued. Courier services were established for sending secret messages between Bikini and Washington, D. C. Photographs were developed only by authorized Joint Task Force One persons, and no photograph was released until it had been found to satisfy the security rules laid down by the Joint Chiefs of Staff.

These security rules seemed to most persons to be reasonable. They permitted discussion of the objects of the Tests, the approximate locations of all target ships, the kinds and numbers of animals placed on the ships, the method of delivering the bombs, the types

** Each woman, too. There were 37 women nurses at Bikini, although few of the 41,963 men there ever caught glimpses of more than a half dozen.*

of scientific information sought. And they permitted inspecting many of the damaged ships before and after the explosions, obtaining statistics on test animals killed, and rough values of the ranges at which ships were sunk or damaged. Approximate figures were given out as to the amount of radioactivity produced, and the degree to which crews would have suffered. Not to be released were facts as to bomb design, exact amount of energy released, exact position of the bomb at the instant of detonation, exact positions of the target vessels, correlations between damage and exact values of range, pressure, etc. More than enough information was released to permit the world to see both the character and magnitude of the havoc a single atomic bomb can cause.

The most important of General Betts' positive functions (see Appendix 2) was providing the public with a stream of accurate information. To General Betts and his Public Information Officer, Captain Fitzhugh Lee (Navy), it sometimes appeared that the public went out of its way to conjure distorted pictures of the planning and expected results. Some groups were prone to believe that the target ship array was supposed to resemble a typical fleet at anchor, or a fleet at sea. Some persons tried to build up the Operation into an "Air Forces versus Navy" struggle, in which the goal was to see how many ships the Air Forces could sink with one bomb. Others pictured the Tests as more-or-less rigged shows to "prove" that the Navy was not obsolete; they hinted that the Navy feared most of all, and for that reason was avoiding, the deep-under-water explosion of an atomic bomb with its resulting possibility of extensive damage to ships.

But perhaps the commonest distortion was as to the great calamities which were to threaten. Massive underwater landslides might be tripped off; enormous tidal waves might sweep across the Pacific and devastate its shores; the very crust of the earth might be parted, with unimaginable consequences. The chain reaction in the bomb might spread to the water and the whole ocean might explode. Conjecture had no limitations except man's imagination.

The majority of the misconceptions were gradually dislodged by the steady stream of facts issued to press and radio by Captain Lee and his assistants. Within the first few weeks after the creation of the Task Force, Captain Lee had prepared and issued over forty bulletins, which covered nearly every phase of the Operation. Open news conferences were held too. Admiral Blandy and his staff sat across the table from dozens of the country's best correspondents and gave spot answers to their searching questions concerning the atomic tests.

Again and again they explained that the Tests were not Navy tests but *Joint* tests, to be carried out at the request of the Joint Chiefs of Staff and with the authorization of the President and Congress.* They reiterated that the Tests were not designed to prove or disprove anything, but merely to find the facts. They pointed to charts showing that the planned target arrays bore no resemblance to fleets in harbor or at sea, but were designed specifically to produce the optimum amount of technical data. Continual effort was made to deflate predictions of catastrophes.

The last key to good public relations was provided when authorization was arranged for inviting press and radio to send representatives to Bikini. The Joint Chiefs of Staff recommended such a course on January 10, 1946, and the Secretaries of War and Navy gave their endorsement on February 5; final approval came from the White House on March 14. Actual attendance was as follows:

	Test A	*Test B*
Representatives of U. S. press, radio, pictorial services, magazines, etc.	114	75
Foreign press, one representative from each nation having membership in UN Atomic Energy Commission, plus two representatives from Great Britain	10	8

* *Even the task of keeping the public informed was made a* joint *activity. On March 8, 1946, the Joint Chiefs of Staff requested that individual Services cease expressing to the press their own fragmentary news and asked that they channel all news releases through the Task Force Commander's central public relations group.*

Selecting the individuals was not easy. Far more persons applied than could be accommodated. It was essential to work out some impartial scheme of issuing the invitations. One view was: Invite individual persons directly, by name. The opposite view was: Pick the news agencies, and let them name their own representatives. This latter view finally prevailed. Another nice question facing Captain Lee was: Should he try to select news agencies most experienced in reporting scientific and military matters, or should the selection be broadened to include all kinds of news agencies, regardless of the bents of their experience? The latter course was chosen. Without doubt the result was that some representatives unskilled in technical and military reporting made the trip; but a redeeming advantage was that accounts of the Tests appeared in nearly every type of newspaper and magazine, including even some of our most "feminine" magazines.

Through a specially-created committee, press and radio agencies were enlisted in helping to make the final choice of the agencies to be invited.

Captain Lee arranged for the majority of the press and radio men to be transported to Bikini in the APPALACHIAN, press headquarters ship, and for others to go by air. To avoid repeated problems of protocol, Captain Lee arranged that preferences in living quarters and various nonprofessional privileges were to be granted according to age, the oldest correspondents being most favored.

To help those correspondents who were starting off "cold," Captain Lee arranged, besides press conferences, various orienting schemes. Lectures were arranged; motion picture films were prepared and shown; press packets of pamphlets on subjects ranging all the way from nuclear physics to the history of the Central Pacific were prepared and distributed. No effort was spared in making this the *best*-reported as well as being the *most*-reported technical experiment of all time.

In the Nucleonics Age it is still true that a single picture is worth a thousand words. Recognizing this, General Betts asked Captain R. S. Quackenbush (Navy) to plan an adequate nontechnical photography program, whereby the press men and the world at large could see vicariously all that security would permit. His enormous program is described in a later chapter, in connection with technical photography.*

A sincere gesture of international goodwill was made by inviting foreign observers to see the explosions. The desire to invite foreign observers was expressed by the Services and by large sections of the public even before the Task Force had been formally created. The Joint Chiefs of Staff were considering the matter as early as January 10, 1946. The State De-

** A selection of over 225 of the photographs taken by Captain Quackenbush's group is presented in "Operation Crossroads, Official Pictorial Record," published by William H. Wise & Co., Inc., New York, New York.*

partment went on record in favor of the proposition, and, on March 14, President Truman approved the plan.

The Secretary of State accordingly asked our ambassadors in the eleven foreign countries having membership in the United Nations Atomic Energy Commission to invite those countries to choose their official witnesses. The countries and their representatives are listed in Appendix 6.

The twenty-one global representatives selected assembled in Washington, D. C., and went by special train to Oakland, California. There they boarded the PANAMINT, Bikini bound.

Besides these foreign observers and a few participating scientists from Great Britain, there were eight additional observers from Great Britain, four from Canada, and one from Australia. There were also a few press representatives invited from foreign countries.

But Colonel H. B. Smith, Head of the Nonparticipating Observers Section, had many other observers to shepherd also. There were fourteen Congressional observers (see Appendix 7), eighty-seven Army and Navy observers, and twenty-two civilian scientist observers. Congressional observers were considerably fewer than expected. The Joint Chiefs of Staff originally set a quota of sixty but the invitations were not issued until late — after June 14, 1946, when Congress gave final approval to the Tests.

OPERATIONS PLANNING AND DIRECTION

Nearly every movement of the Task Force's 242 ships and 156 airplanes was made, of course, by direction of the Task Force Commander; but it was the responsibility of Captain C. H. Lyman (Navy), Assistant Chief of Staff for Operations, to plan and coordinate all such movements. Captain W. C. Winn (Navy) assisted in the directing of movement of vessels. He maintained records showing where each ship was, who was in command, what its mission and destination were. When additional ships were required, it was his job to obtain them; when certain ships were no longer needed, it was his job to see that they were reassigned.

Captain Lyman was assisted by Colonel W. D. Ganey in the planning and directing of air operations. He was assisted by Captain K. M. Gentry (Navy) in communication matters, including radio, television, and transmission of radio-photographs; a schedule of 348 individual radio frequencies was arranged, of which 163 were assigned to command and administrative groups, 107 to instrumentation groups, and 78 to press and radio groups. In the crucial matter of analyzing and predicting weather, Captain Lyman was assisted by Colonel B. J. Holzman and Captain A. A. Cumberledge (Navy), outstanding experts in aerology.

Perhaps the two most important observer groups at Bikini were the Joint Chiefs of Staff's Evaluation

Board and the President's Evaluation Commission. The Evaluation Board, whose members are listed in Appendix 4, was responsible directly to the Joint Chiefs of Staff and was to make careful technical study and comprehensive conclusions. The Evaluation Commission, whose members are listed in Appendix 5, reported directly to the President. It was not expected to make any highly technical studies. Preliminary reports by these bodies are included in this volume as Appendices 10, 11, 12, and 13.

LOGISTICS FUNCTIONS

The supply, transportation, and maintenance of men and materials was the responsibility of Brigadier General (now Colonel) D. H. Blakelock, Assistant Chief of Staff for Logistics. The breadth of his work is indicated in Appendix 1. He was responsible for transporting the Task Force's 42,000 men and providing them with military, technical, and personal equipment. (Approximately 1300 persons were flown from continental United States to Bikini and back; approximately 440,000 pounds of freight were flown from continental United States to Pearl Harbor or to the Marshall Islands.)

Keeping these four fast-working staff divisions working without any crossing of purposes was no easy matter. Frequent staff meetings proved helpful. Here, flanking an enormous table set in the center of a carpeted and air-conditioned room, Admiral Blandy and his deputies would confer for an hour or two. Problems were presented and comments were invited from all present. In each instance Admiral Blandy or his Chief of Staff would make a summary as to the agreed-on-course and designate one man to take the necessary action.*

Between formal meetings there were innumerable informal meetings. Staff officials whether from Army or Navy were given adjacent offices so that they could

* *The author and other civilians present found these meetings impressive, both in their democratic method of procedure and the quick availability of facts. Almost never did an officer have to consult notes, or ask to get the information later. Usually, he had the answers at the tip of his tongue; and if he did not, he was flanked by one or two junior officers instantly ready to cite case and number. Again, since representatives of all Service groups were present, almost no question was outside the scope of the meeting.*

One mildly humorous case of failure to obtain straight-off a useful answer has stuck in the author's memory: An urgent dispatch was sent off to the advance group at Bikini to find whether the coral heads obstructing navigation in the Lagoon were being removed successfully. But the actual form of the message was to the effect: "Are you having any difficulty in removing the coral heads?" The laconic reply came back: "Yes." Admiral Blandy's comment drew broad grins from all the conferees: "We don't care whether he's having difficulty; of course he is. All of us have our difficulties. Send another dispatch and ask if he is overcoming *his difficulties."*

Clairvoyance was effectively used by Admiral Blandy in solving one problem — a problem as to what to do with the unconsumed beer which might remain on Bikini Atoll during the evacuation for Test A. After other officers had proposed various solutions, Admiral Blandy spoke up: "There really isn't any problem; if I know anything about military men, there won't be any unconsumed beer."

exchange memos and drafts promptly. Telephone directories of Crossroads officials were issued every two weeks, to keep pace with expanding forces and constantly shifting quarters. Throughout the day, streams of new personnel would crowd in, new desks and file cabinets were wheeled in on creaking dollies; newcomers, unable to find empty chairs would perch on desk tops or sit on staircases In the midst of this apparent confusion, the ubiquitous telephone men worked with pliers and screwdrivers.

A mammoth Operation Plan was prepared—a plan so vast and detailed as to suggest the Book of Fate itself. The Plan contained several thousand large, finely-printed pages* and served as a bible throughout the Operation. Heart of the Plan was a set of twenty-nine annexes, each a veritable encyclopedia on all plans relating to a given phase of the Operation. The titles of the Annexes are illuminating; they are:

Movement Plan
Logistics Plan
Communication and Electronics Plan
Security Plan
Safety Plan
Air Plan
Instrumentation Plan
Bikini Evacuation Plan
Re-entry Plan

* *It is a great tribute to the Government Printing Office that it could print and deliver this enormous plan in the space of a very few weeks.*

Plan of Operation on A-Day
Plan of Operation on B-Day
Photographic Plan
Salvage Plan
Army Ground Group Plan
Public Information Plan
Target Layout Test A
Target Layout Test B
Oceanographic Survey Plan
Harbor Information
Aerological Plan
Boat Pool Plan
Typhoon Plan
Ship Preparation Plan
Reboarding and Inspection Plan
Air-Sea Rescue Plan
Nonparticipating Observers Plan
Rongerik Evacuation Plan
Reports
Drone Boat Plan

Several of the annexes, which themselves contained voluminous appendices and even appendices to appendices, were many hundreds of pages in length, and contained a wealth of charts, graphs, etc.* Civilians or others who may have expected the Task Force to be directed by a multitude of impromptu decisions made in the field were impressed with the completeness with which problems were anticipated and categorically

* *The Operation Plan was so complete that the writer, who studied it with some care, had throughout the Operation the impression of attending a good Technicolor motion picture of a recently-read book.*

solved long in advance. Even the exposure times for the ten thousand most important photographs were worked out and clearly specified in the Operation Plan.

One obvious advantage of the detailed, long-in-advance planning was that it left the Task Force Commander and his assistants relatively free to solve the few unpredictable problems that were bound to arise. Principal unpredictable matters were: weather, number of damaged target vessels which would require beaching, extent of radioactivity to be found on target vessels. As we shall see later, weather forced postponement of the "Queen Day" rehearsal of Test A, and all but forced postponement of the "William Day" rehearsal of Test B. It caused a half-hour postponement of Test A. The radioactivity remaining on target vessels after Test B was much more intense than most persons had anticipated; considerable delays in reboarding, inspecting, and report-writing resulted, and the final disposal of the surviving vessels was greatly complicated.

The planning was good. As later chapters show, the Task Force assembled without incident and the target vessels were moored in the positions decided on weeks in advance; both Tests came off on the intended days; no one was injured by the explosions; and a great mass of technical information was gathered. A vast administrative machine had proved its power.

4. TECHNOLOGICAL OFFENSIVE

Crossroads was above all a technical operation. All planning was subservient to the primary mission: collecting technical information.

Rear Admiral W. S. Parsons, as Deputy Task Force Commander for Technical Direction, led the technological offensive. As Assistant Chief of Naval Operations, Special Weapons, he played a large part in formulating Navy opinion as to how the Tests should be arranged; and, as ranking Navy member of the joint LeMay Subcommittee, he helped draw up the formal directive.

His biggest job was analyzing the technical requirements, breaking them into logical divisions, and setting up the necessary technical administration. With the assistance of Navy Captains Horacio Rivero and F. L. Ashworth, he found that the required technical activities could be aranged under four distinct headings. To handle these activities, he set up two technical administrative groups and two advisory positions.

The largest of the two technical administrative groups was made responsible for the following: (1) preparing the target vessels, exposing them to the two explosions, determining the damage, and disposing of them; (2) the same for a wide variety of Army and Navy equipment, including airplanes; (3) exposing goats, pigs, rats, guinea pigs, mice, determining injury, studying the symptoms, and finding the best methods of diagnosis and treatment; (4) decontaminating those ships made radioactive by the explosions. This group, which ultimately involved more than 10,000 men, was directed by Rear Admiral T. A. Solberg, who assumed the title of Director of Ship Material.

Perhaps the most publicized of the two groups was that containing the 500 scientists responsible for measuring pressure, light, nuclear radiations, wave height, etc. In charge of this group was Dr. R. A. Sawyer, Technical Director.

Captain G. M. Lyon (Navy, Medical Corps) was named as Safety Adviser. His job was to prevent injury to personnel, either from hazards of normal type or from hazards (other than nuclear radiations) peculiar to this Operation. This included hazards to persons first reboarding the target vessels:

Mechanical hazards, including danger from falling objects, slippery (oil-covered) surfaces, weakened ladders, decks, gratings, and weakened tanks under pressure.
Drowning in flooded compartments.
Fires; escaping steam; hot surfaces.
Electrical shocks due to damaged wiring and short circuits.

Chemical hazards due to carbon monoxide, carbon dioxide, nitrous gases, alcohol and other vapors, ammonia, corrosive acids and alkalies, creosol cleaning solutions.

Miscellaneous hazards, including contaminated drinking water and food, escaping gases from chemical warfare munitions, secondary explosions of ammunition or acetylene.

Enumerating the hazards was simple, but to warn the thousands of men involved and instruct them in safe practice required much planning and thorough training.* Captain Lyon's designation as Safety Adviser was a logical one in view of his extensive wartime experience in chemical warfare technology and his close association with the Atomic Bomb Project.

Colonel S. L. Warren (Army Medical Corps) was made Radiological Safety Adviser to Rear Admiral Parsons and also to Admiral Blandy. His job was the

* *Accidents were very few. No one was injured by the explosion, and no one was seriously injured even by indirect effects such as radioactivity. However, five fatal accidents occurred. A Navy enlisted man, R. L. Mangum, Seaman First Class, drowned on March 25, 1946. Captain J. E. Bishop (Army) was killed on June 24, 1946, as a result of being struck by the propeller of a B-29 which was warming up on the airstrip at Kwajalein. A Navy enlisted man, J. D. Moran, Radioman First Class, was accidentally electrocuted on July 4, 1946, on the* ALBERMARLE. *Lt. W. H. William (Navy) was killed on July 9, 1946, in an airplane crash on Roi. J. R. Reagan, Seaman First Class, died as a result of methyl alcohol poisoning on July 24, 1946.*

unusual one of advising as to dangers which would lurk in the invisible radioactive materials scattered on target vessels, in lagoon water and even in the atmosphere itself. Col. Warren brought with him years of experience gained while he was Chief of the Medical Section of the Manhattan Engineer District.

Preparing the target ships and support ships was an enormous job. The job was far greater than might be expected by persons unfamiliar with the problems. Admiral Solberg was called upon to execute quickly an enormous planning program and to organize the extensive cooperation to be obtained from all major shipyards, from the Office of the Chief of Naval Operations, from the Commander-in-Chief of the Pacific Fleet and Pacific Ocean Areas, and from nearly every Naval Bureau.

Perhaps the simplest part of the work was preparing the support vessels, listed in Appendix 8. There were 149 of these vessels, 36 of them being of considerable size, *i.e.,* over 10,000 tons.

Considerable remodeling was required on many of the ships. On the flagship MT. McKINLEY, forty more desks were installed and air conditioning was provided in two wardrooms and three staff cabins; television and radio teletype equipment was installed also. On the press ship APPALACHIAN a broadcasting studio was built and television and radio teletype facilities were installed; additional accommodations were provided for officers and press representatives, and several wardrooms were air conditioned. Air conditioning equipment was installed in certain parts of the PANAMINT and BLUE RIDGE also.

ALBEMARLE and CUMBERLAND SOUND, to be used principally by the Los Alamos group, were converted into great floating laboratories equipped with nearly every kind of machine tool and electrical instrument. Special laboratories were installed in the KENNETH WHITING, WHARTON, HAVEN and AVERY ISLAND. BURLESON, the animal ship, was remodeled into a great dirtless farm, a palatial hotel for animals; biophysics, radiobiology, pathology, and hematology laboratories were installed also. LSM-60, the central or Zeropoint ship for the second test, was remodeled to permit lowering the bomb, in its watertight caisson, through a central bottomless well. Special photographic laboratories were built in SAIDOR and other ships participating in the enormous photographic program.

These remodelings were completed rapidly. The majority of the work on support ships and target ships was done in the Naval Shipyards at Philadelphia, Bremerton, Mare Island, Hunters Point, Terminal Island, and Pearl Harbor. The work was based on detailed plans prepared by the Bureau of Ships.

Many kinds of policy problems had to be solved before the shipyards could begin preparing the target ships — listed in Appendix 9. One fundamental question was: Should the ships be stripped of all equipment of value, or should they be left fully equipped? Economy-minded persons favored removing much of the valuable equipment such as guns, rangefinders, radar equipment; but others pointed out that the equipment must be left on the ships if the tests were to yield the maximum information. The final decision was as follows: Items of historical interest and all items actually needed for our active fleet, except for sample items, should be removed; other equipment should be left aboard.

How much repair work should be done was another puzzle. For results to be fully significant, the target ships should resemble normal, fighting ships; that is, they should be in good shape. But a number of the ships were in fact *not* in good shape. A few had serious war wounds, patched only in makeshift manner; it was clear that the old wounds might be re-opened with misleading ease. Similar questions arose as to ships' machinery, ordnance equipment, etc., which suffered damage during the war. The decision was made that the ships and their equipment should, wherever feasible, be put in first class condition. The amount of repair work entailed was very great; but had this work not been done, it would have been almost impossible to tell after each explosion what damage was really caused by the explosion, and what damage should be attributed to prior circumstances.

An unusual "must" — not normally applicable to *manned ships* — was making the ships almost perfectly watertight. A fact not fully realized by the public is that the majority of warships — even warships which have never seen battle — leak slightly. Particularly in older ships, it is almost impossible to make all joints perfectly tight. The slight continual in-flow of water is of no consequence ordinarily; it is easily pumped out. But in this Operation, where the ships might have to remain for weeks without crews and without pumps operating, such leaks might be very serious. There was some danger that the captured Japanese ships NAGATO and SAKAWA might actually sink from this cause if they were left unattended for three or four weeks.

Admiral Solberg's group gave much attention also to *internal* watertightness, a subject which may appear to laymen to be of little importance, but was actually of great importance. Ships expect to take punishment in battles, but place reliance on internal watertightness to keep them afloat and mobile. Ships are, in fact, honeycombs of separate compartments.*

In battle, hatches between compartments are closed securely. If a shell, bomb, or torpedo opens a hole beneath the waterline, water pours in; but if the ship's watertight integrity is good, only the compartments adjacent to the hole are flooded. Other compartments

* *Exact numbers of watertight compartments in modern ships are kept secret. But it is no secret that for a modern U. S. battleship, for example, the number of such compartments is nearer 1000 than 100.*

remain dry. Thus the ship can continue to cruise and to fight.*

But it is very difficult to maintain internal watertight integrity in older ships. In the first place, the older ships have far fewer compartments. Secondly, such ships have usually undergone considerable repair and remodeling, which means new holes cut through partitions for pipes, wiring, etc. It is almost impossible to seal these holes perfectly. Tests can be made, using compressed air, to see how tight any given compartment is, and the leaks can be found; but the job is a very big one.

Leaks between compartments would be especially serious in the target ships at Bikini. A typical ship might be left unmanned, with pumps shut off, for days or weeks. Water pouring into a single compartment might slowly spread throughout the ship and sink it. This, of course, would give a very false impression as to the effectiveness of the bomb; even a skeleton crew might have prevented the flooding.

Admiral Solberg's job, therefore, was to test watertight integrity and to improve it so that the ships would have normal survival power, even when one or

* *During the war there were several occasions when a ship not only survived but actually continued fighting after several holes had been torn in her hull plating below the waterline; there were even instances where ships were broken in halves, and yet one or both halves were kept afloat. The so-called "unsinkability" of the largest warships derives in fact more from effectiveness of compartmentation than from mere toughness of exterior.*

a few holes were made in the hull by the great explosions. Thousands of compartments were air-tested; innumerable holes were filled, and the stuffing boxes re-stuffed.

Besides stripping the target ships of valuable material and putting them in good physical shape, the construction and installation of special mounts for scientific instruments was called for. Displacement and acceleration gages were to be mounted below decks, and a great variety of gages and automatic recorders were to be mounted topside. These mountings had to be very heavy in many cases to withstand the severe shock wave expected. Special stands or cages were installed for the test animals. Special fastenings were prepared for the wealth of army material to be exposed on the upper decks. Much special electronics equipment was readied.

Even before the target ships began heading out to sea, bound for Pearl Harbor and then Bikini, the enormous task of inspecting them was being planned. The two great explosions might create a wealth of damage; but unless the damage were cataloged effectively, much value would be lost.

Admiral Solberg's technical staff found that no ordinary inspection procedures would do. The procedures used during the war were studied* but were found not

* *During the war a very thorough system of inspections had been worked out, for example, by the Board of Inspection and Survey, Forces Afloat.*

to be adequate for the peculiar purposes of these Tests. A whole new set of instructions was therefore worked out and printed; it contained over 250 pages, and showed exactly how each part of the ship and each piece of equipment should be inspected. Equally important, it proposed standard forms for reporting the inspection results. Without uniform reporting, it would be almost impossible to add up the information to get meaningful totals and comparisons. Two thousand copies of these instructions and five thousand inspection notebooks were distributed.

There was no formal parade of ships to Bikini, and little drama. Ships put out from east coast Navy yards as early as March 4, 1946. By mid-March the Panama Canal was making its contribution to the Operation. Many of the ships had left the west coast shipyards by early March. Ships were drawn from remote Pacific bases also, including Manila, Shanghai, Guam, Okinawa, Saipan. The Japanese battleship NAGATO came from Yokosuka, Japan, and the cruiser SAKAWA came from Otake, Japan. The German cruiser PRINZ EUGEN had come from Germany, via Boston, Philadelphia, and the Panama Canal.

The great size of the Task Force became apparent at Pearl Harbor, where, in mid-May, over one hundred of the ships were assembled. But Pearl Harbor, familiarly known as "Pearl" or "P.H.," was more than an assembly point; its huge shipyard had taken on the work of preparing a large number of the ships.

Here also many of the target ships were loaded with ammunition and fuel.

The migration of target ships towards Bikini was nearly completed by June 1. The focus of interest began to shift towards *results.*

5. SCIENTIFIC OFFENSIVE

Science's broad scope was clearly evidenced at Bikini. Boarding the ships and airplanes heading for Bikini were nuclear physicists, chemists, mathematicians, spectroscopists, roentgenologists, biophysicists, biologists, veterinarians, hematologists, piscatologists, oceanographers, geologists, seismologists, meteorologists. Their work attracted particular attention because of its novelty. New kinds of phenomena were expected; new kinds of instruments had to be built. No one could say whether the instruments would work properly, whether they would successfully cope with the extremes of pressure, radiation intensity, etc. The scientists were working at the frontier of experimental science; some of them were working far beyond the known frontiers. They were filled with curiosity as to what information their instruments would capture from the uncontrollable fury of the explosions which had never been witnessed by such a large body of scientists.

Dr. R. A. Sawyer, Technical Director, arrived at Bikini on May 29, 1946. From his headquarters in the KENNETH WHITING, he and his assistants coordinated the final scientific preparations. Principal assistants were Dr. E. W. Thatcher, Captain F. L. Riddle (Navy), Commander E. S. Gilfillan, Jr., Commander A. W. McReynolds, Lieutenant Commander J. K. Debenham, and Ensign H. M. Archer.

These men had little time for sunning on the upper deck, or watching the evening movies. Dressed in short-sleeved khaki shirts, abbreviated khaki trousers, and sneakers, they worked in their small, hot, humid quarters from early morning until late at night. They had to study final plans, iron out the few minor inconsistencies, locate men to help out on lagging projects. They had to inspect installations, prepare progress reports, attend staff meetings on the MT. McKINLEY.

The Venice-like transportation system was an obstacle. Each trip to inspect apparatus or attend a meeting meant traveling to another ship. Such trips usually took 10 or 20 minutes — if a launch was available. There were, of course, hundreds of small boats in the area, and all day they dotted the clear blue expanse of the Lagoon, their wakes crossing and interlacing. But the supply could not keep up with the demand. To make optimum use of these boats, scientists and others worked out boat pools, planned their work so that the minimum number of trips would be required. But throughout the Operation they were careful to cultivate the friendship of the boat dispatchers.

Dr. Sawyer had, of course, set up the necessary administrative organization long before he left Washington, D. C. (See Appendix 1). Few final readjustments were required at Bikini. In creating this organization, Dr. Sawyer made every attempt to make use of existing research groups; for by using a group already staffed for a particular kind of research, results could be obtained rapidly, with few personnel problems, little need for any extensive study, and almost no outside supervision.

Although the administrative organization was designed to achieve maximum speed with minimum outside supervision, it was not necessarily based on simple scientific lines. For this reason, Dr. Sawyer arranged coordinating groups to see that each scientific function was adequately taken care of. The functions covered included bomb operation, pressure and impulse, oceanography, electromagnetic propagation and electronics, radioactivity, optical radiation, nuclear radiation, technical photography, and remote measurements of various phenomena.*

Dr. Sawyer's organization included more than 550 scientists and engineers. The majority of them were civilians lent by the Services or by civilian agencies, foundations, and universities; many were Army and Navy officers. During their cooperative activities, civilian and Service personnel worked with little re-

* *Remote measurements included (1) measuring tide data at Midway, Wake, Kwajalein, and Eniwetok Islands, (2) recording shock at these islands, and (3) tracing radioactivity in the Central Pacific.*

gard to protocol; they sweated side by side to get the apparatus ready for recording the full measure of the great explosions of A-Day and B-Day.

PRESSURE

Pressure was to be king on A-Day, when the bomb was to explode several hundred feet in the air. It was expected that giant waves or intense gamma radiation might do the worst damage on B-Day, day of the underwater explosion; but few doubted that pressure would wear the crown on A-Day.

Air pressure may not sound fearsome. We are — literally — under pressure at all times. The air around us is compressed by the mere weight of overlying air. Every part of our bodies is subjected to a steady pressure of 14 or 15 pounds per square inch. Yet we sleep and breathe with ease.

But although it is true that steady pressures of 10 or 20 pounds per square inch go almost unnoticed, it is equally true that sudden increases in pressure (overpressure) can be remarkably effective. Fast, recurrent pressure changes as slight as one billionth of a pound per square inch are easily detected by the ear; many a building can be toppled by a sudden, transient, pressure increase of one pound per square inch. Transient overpressure crushed thousands of buildings at Hiroshima; it was to sink five ships on A-Day.

Pressure experts cannot talk long about overpressure without bringing in the Mach Stem, a scientific anomaly which makes pressure waves doubly destructive to houses, ships, or other objects situated just above a large immovable surface. Near the end of the last century an Austrian scientist named Ernst Mach was studying electrical sparks — using apparatus plentifully coated with dust and soot. He noticed that whenever a spark was produced, dust was scoured away from a nearby, dust-covered surface. He noticed also that the scoured area was curiously limited in its extent.

The explanation is now well known. It is worth recording here since it had such a great influence on the planning and results of the A-Day explosion at Bikini. When an explosion occurs just above the surface of the ground (or say, just above the surface of a lagoon), the spherical pressure wave spreads in all directions. The part of the wave which strikes the ground is reflected. If the intensity of the direct and reflected waves is not too great, the waves go their separate and easily-predicted ways. But if the pressure waves are very intense, then the whole situation changes: the waves affect one another curiously. Near the ground, in what has come to be called the Mach Stem region, the reflected wave finds itself close on the heels of the direct wave, in fact practically *in* the direct wave. Now it is a fact that when one intense wave travels more or less within another intense wave, it travels unusually fast. The result is that the reflected wave tends to catch up with — and even coalesce with — the direct wave. Actually the combined wave is no longer spherical, but nearly cylindrical or stem-like. All this happens, of course, only in the limited region where the two waves are initially fairly close together — *i.e.,* near the ground.

The scientific result is that near the ground the pressure is now far greater than could be produced by the direct or reflected waves singly.

The tactical implications predicted for A-Day were ominous. The experts knew that a large fraction of the great armada of target vessels would find themselves in the Mach Stem region; what had been a scientific curiosity might mean destruction for many warships. Interest on this subject thus rose to an especially high pitch.

Mere interest, of course, was not enough. Pressure gages were needed. Some of the simplest yet most effective gages were those devised by Dr. W. G. Penney, a British scientist. Back in 1945 when he was working at Los Alamos, he made the daring guess that the humble tin can would prove to be one of the best "instruments" for measuring the terrific pressures produced by atomic bomb explosions. He soon showed his guess to be correct. He demonstrated that whenever a five-gallon gasoline can was partially crushed by a sudden pressure wave, the degree of crushing depended on the exact intensity of the pressure wave. For example, an overpressure of only a few pounds per square inch might reduce the can's volume to 80 percent of the original volume; but a more extreme overpressure might reduce the volume to 10 percent. Cans are cheap; hundreds may be used, and the average effect can be measured with accuracy. (The decrease in the can's volume could be measured simply by filling the can with water, weighing it, and making a comparison with the weight of a filled *uncrushed* can). Many other instruments were equally ingenious.

Dr. Penney and his assistants, collectively known as the Pressure Group (Cans and Drums), experimented with other gages of equally crude sort.* They were especially keen to hit upon gages good for measuring very high pressures. One type developed consisted of a sort of pan-pipes or harp, of small pipes of graded lengths. When the pressure wave strikes, the pipes are bent; long thin pipes bend most, and short fat pipes least. With the help of laboratory ex-

* *This Group included six subgroups, as follows:*
Air Blast Subgroup, headed by Dr. C. W. Lampson
Underwater Subgroup, headed by Dr. A. B. Arons
Low Frequency Subgroup, headed by Dr. J. V. Atanasoff
Radiometry Subgroup, headed by Comdr. S. S. Ballard
Pressure-Time Subgroup, headed by Dr. J. E. Henderson
Service Subgroup, headed by CWO J. P. Orr.

Captain L. W. McKeehan (Navy) served as Adviser. Personnel was drawn principally from the Navy's Bureau of Ordnance, the Naval Research Laboratory, and the David Taylor Model Basin; pressure experts were borrowed also from various universities, notably the University of Washington in Washington State.

periments and some mathematics, Dr. Penney learned how to translate bends into pressure values.*

Dr. Penney's group was not the only one striving to extract knowledge from the pressure wave. The problem was attacked on a very broad front by the powerful Bureau of Ordnance Instrumentation Group. This Group, led by Captain A. E. Uehlinger (Navy) and under the technical direction of Dr. G. K. Hartmann, surveyed all known types of pressure gages.

But finding suitable gages was difficult; there were many hard-to-meet requirements. Some of these requirements pervaded the other scientific fields, and were thus of especial importance.

Most important was the requirement that the gages leave permanent records of their response; there would be no one on hand to watch them. Among the various automatic recording schemes available were: (1) ink-recorders, in which a small fountain pen writes its crude but significant message automatically on a sheet of paper mounted on a slowly-rotating disk or drum; (2) scratch-recorders, in which a needle scratches its message on a wax-coated disk or drum; (3) magnetic recorders, in which variations in pressure are converted into variations in degrees of magnetization of a short segment of a slowly-moving steel wire or tape; (4) optical recorders, in which pressure

** In his official tour of inspection of Hiroshima and Nagasaki, Dr. Penney had found that the pressure waves there had left readable records in the form of bent fence posts, sign posts, etc.*

variations cause a small beam of light to move across a slowly-traveling strip of photographic film, to be developed and analyzed later; (5) telemeter-recording systems, in which pressure values are actually broadcast by small, automatic, radio transmitters to waiting recorders located in some convenient places several miles away; (6) permanent-deformation gages, such as the Penney cans, which undergo permanent deformations easy to interpret.

A second requirement was that the gages be really rugged. Despite the need for using ingenious recording systems, the gages and their mounts must survive the terrific overpressure. It is pointless to use a precision gage which is promptly flattened or blown overboard.* Hence delicacy was not a characteristic of the instrument cases taken to Bikini; on the contrary, many of the designers enclosed their instruments' delicate works in cases built of 2-inch-thick steel which could withstand the pressure.

In the third place, the gages must resist corrosion. In the hot humid air, metal objects corroded unusually rapidly. Aluminum apparatus was, of course, very vulnerable to salt water. Thus corrosion-resistant metals were used ordinarily for exposed working parts, or waterproof coatings of paint or lacquer were applied.

* *In the Alamogordo test of June 16, 1945, a number of instruments failed to stand up to the unprecedented pressures. Some were crushed, others were torn loose and thrown considerable distances.*

In the fourth place, the gages must be able to bide their time. Even if the explosion were to be postponed slightly, the instruments must be ready at the new H-Hour. Batteries must not run down; recorders must be ready. In many cases the problem was solved by installing special starter-clocks; in other cases "black box" remote-controlled starting devices were used. (These are discussed in Chapter 7.) In a few instances, the instruments were started by the flash of light emitted by the exploding bomb itself.

A difficulty peculiar to the measurement of the pressure wave was designing instruments which would operate fast enough to catch the pressure wave at its instantaneous peak. For at any given point (say on a target vessel only a few hundred yards from the Zeropoint) the pressure would, of course, increase extremely suddenly — so much so that the pressure experts, when drawing sketches of the wave, usually pictured the wave as having what they called a "square front." After its extremely rapid rise, the pressure would, of course, decrease again nearly as rapidly; then for a moment the pressure would actually fall to less than normal, in what is called the suction phase. Obviously a slow-acting gage would become confused by the many sudden changes in pressure, and would present only a sort of average value. Unfortunately, average values would be of little use; every effort was made, therefore, to design fast-acting "massless" gages.

Fortunately, the pressure experts under Dr. Hartmann had faced these problems back in the United States months before. Even during the autumn of 1945 informal exploratory conferences were held among scientists and engineers from the Naval Ordnance Laboratory, the David Taylor Model Basin, and elsewhere. The difficulties were discussed, constructive suggestions were offered, criticized, revised, and slowly elaborated into sound designs. Whiteprints were rushed to the machine shops, finished instruments were tested, taken apart, adjusted and re-assembled.

From many shops and laboratories, crates filled with instruments were started on their way by rail and air freight to the West Coast. The crates were almost always heavy, and stamped SECRET in large letters. Special shipping orders were prepared and guards provided. In all, over 5000 pressure gages made the journey, to snatch permanent meaning from transient chaos.

Even on the KENNETH WHITING, as she steamed westward at 16 knots, the specially-installed machine shop was busy with Ph.D's and technicians working with lathes, drill presses, and the ever-needed screwdriver.

But now, as A-Day approached, emphasis shifted to installing the instruments. Let us look over the kinds of pressure gages which were installed.

1. *Can-Type Peak-Pressure Gage.* This gage has been described on a previous page. Hundreds were

made ready. In the expectation that some would be blown overboard, but might yet be rescued, many of them were tied to floats. An identifying number was marked on each can with a few crude strokes of a paint brush dripping red paint.

2. Pipe-Type Peak-Pressure Gage. This gage also had been described on a previous page. The gages were bolted to the superstructures of the target vessels, particularly the innermost vessels.

3. Ball-Crusher Peak-Pressure Gage. This gage was designed to measure very high pressures. It consists of a strong hollow cylinder of metal, with a slidable steel rod mounted in the hollow. When the pressure wave strikes, the rod is slid forcibly and strikes a small copper ball, flattening it. The greater the pressure, the harder the rod strikes and the flatter the ball becomes. The degree of flattening is later measured, and the pressure value calculated. Hundreds of these gages were made ready.

4. Ruptured Foil Peak-Pressure Gage. This gage was designed for intermediate pressures. It is extremely simple. In one common form, it consists of a sheet of aluminum foil sandwiched between two heavy metal plates. The plates have previously been drilled to provide a graduated series of holes of different size. When the pressure wave strikes, the tendency is for the exposed areas of the aluminum foil to bulge or even burst. Naturally, the larger exposed areas rupture most easily, and the small ones least easily. It is a simple matter, after an explosion has occurred, to inspect the foil, pick out the smallest area which burst, and thus compute the peak pressure. Hundreds of these gages were used. Typically, they were bolted to "Christmas trees," sturdy 9-ft.-high structures of heavy steel pipes. The Christmas trees were ordinarily welded to the upper decks of the target vessels.

5. Deformed Plate Peak-Pressure Gage. This gage was used to measure fairly high pressure. It somewhat resembles the ruptured foil gage in operating principle, but employs a thicker foil or diaphragm, which ordinarily deforms without actually rupturing. A variety of designs were used to accommodate different pressure ranges.

6. Indentation Peak-Pressure Gage. This gage also was capable of measuring very high pressures. Pressure is recorded in terms of indentation produced by a small steel ball forced against a sheet of lead. The greater the pressure, the deeper the indentation.

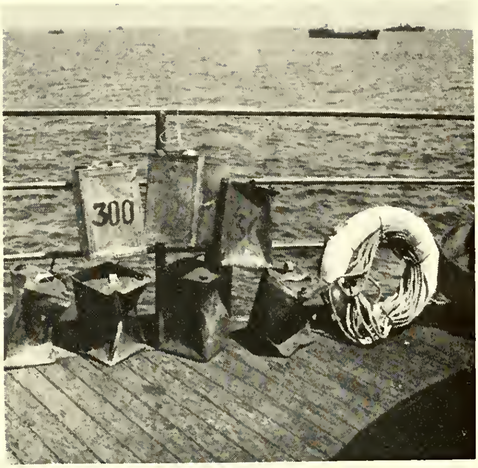
In addition, various gages of more conventional type were used for measuring more moderate pressures. Some of these were of the familiar aneroid-barometer type. Others were of a liquid-trap type, in which the pressure wave depresses the liquid in a tube and causes some of the liquid to become trapped.

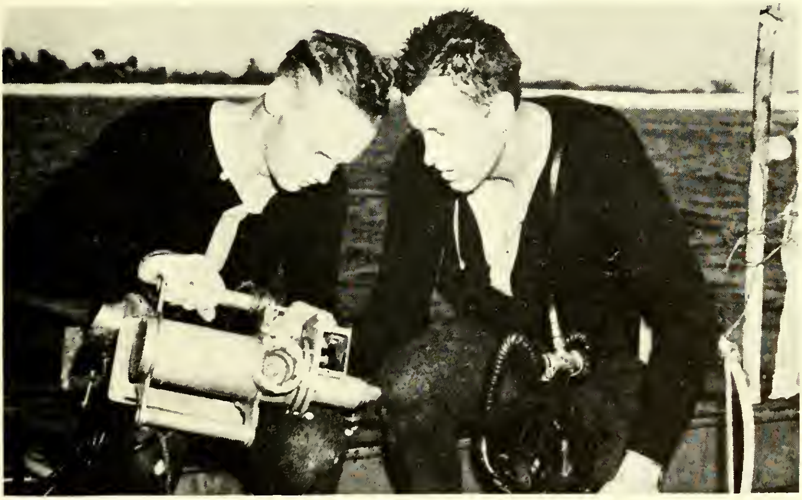
Most elaborate of the pressure gages were those designed to trace the entire rise and fall of the pressure, *i.e.*, the whole life history of the pressure wave as it swept past a given point. In some of these pressure-versus-time gages, pressure values are measured mechanically, by small pistons moving against springs. In others, the principle of operation is electro-mechanical. The pressure wave moves a piston whose motion is opposed by a wire. The wire is thus strained to an extent depending on the pressure, and the wire's electrical resistance changes correspondingly. It is this electrical change which is actually recorded and later interpreted in terms of pressure.

The five thousand pressure gages were placed with great care. The majority were placed topside on target vessels. Many were placed in especially unencumbered positions so that the pressure values recorded would not be invalidated by confusing reflections of the pressure wave. (Nearly every part of the ships' superstructures acted as a crude pressure-wave reflector, creating compound, hard-to-interpret, pressure situations.) Gages capable of recording very high pressures were mounted on the ships nearest the Zeropoint; gages of lower range were used on ships farther out. Gages designed to measure relatively low pressures were placed inside turrets, control rooms, and living quarters to show the pressures crews might experience. Even airplanes scheduled to be aloft near the target area were fitted with special gages.

Nobody expected all the gages to deliver valuable data. A high "disappointment rate" was anticipated. Some of the gages might fail to start; others might be sunk with the ships they were on; others might be dam-

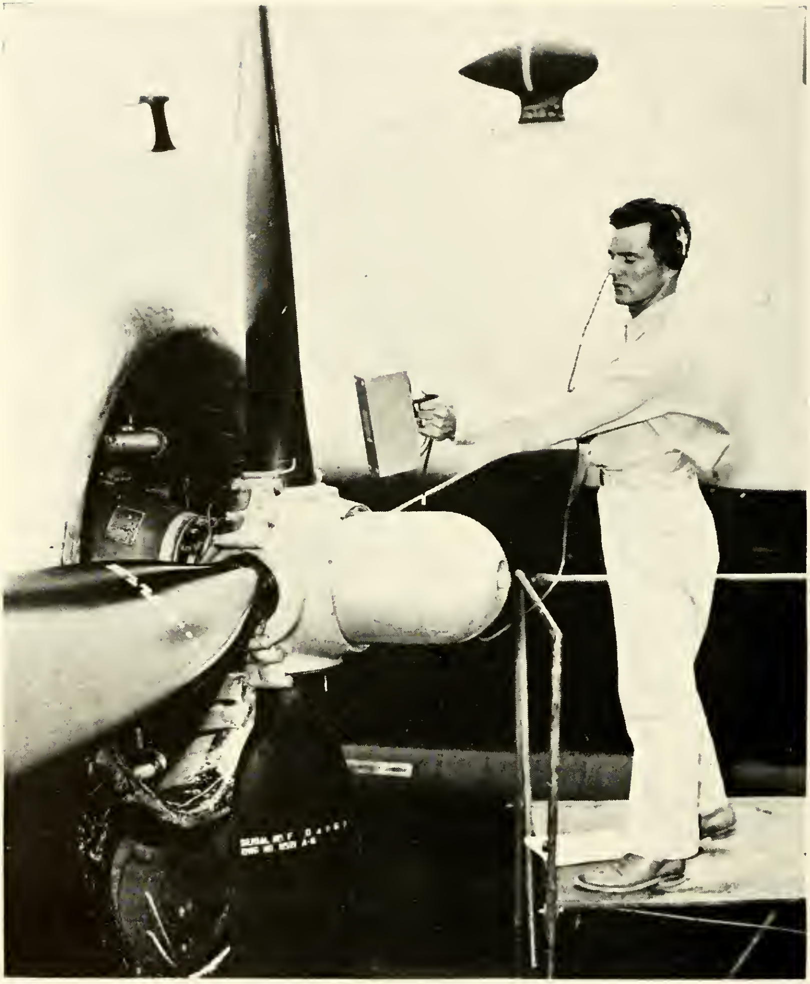
Some of the five-gallon cans which were exposed by Dr. W. G. Penny's Pressure Group at various distances from the A-Day explosion in air. Peak pressures produced at these distances were computed from the degrees of crushing of the cans. Some of the cans were fastened to life-preservers so that they could be recovered if blown overboard.





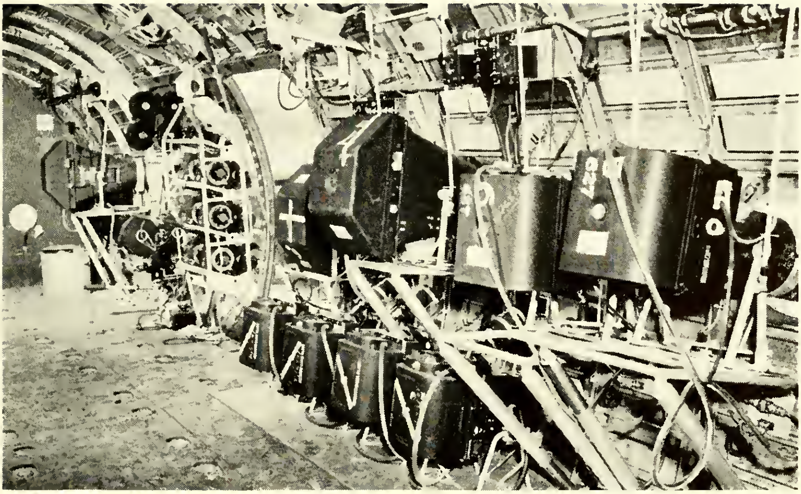
Dr. V. E. Brock (right) and Ensign Richard Cron, Navy diver, examine a camera specially designed for use underwater, as in photographing damaged portions of sunken ships. This work was made difficult after Test B by the potential dangers from radioactivity in the water or in the ships themselves.

Plate 9



A "hot" engine on a B-29 is tested by means of a Geiger counter operated by Colonel R. L. Snider. The B-29's, which were part of Task Group 1.5, were based at Kwajalein. They were used for dropping the bomb used in Test A, photography, observation, and releasing special air-pressure gages.

Plate 10



Besides normal-speed and high-speed motion picture cameras, many mammoth still cameras were mounted in the photographic planes. Eight photographers are needed to operate the cameras in this C-54. The majority of the films were processed in an air-conditioned laboratory constructed at Kwajalein.

Motion picture cameras installed in a C-54 photographic plane. The six Eastman high-speed cameras shown at the right are aimed up and down, right and left, by a single control handle. They operate one after another, automatically, so as to provide an uninterrupted record of the entire course of the explosion. The resulting films were superb.

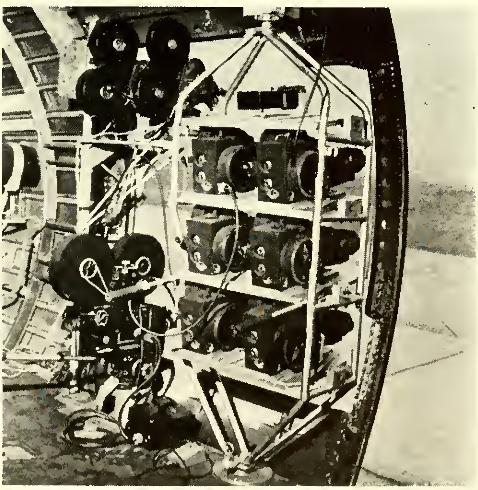
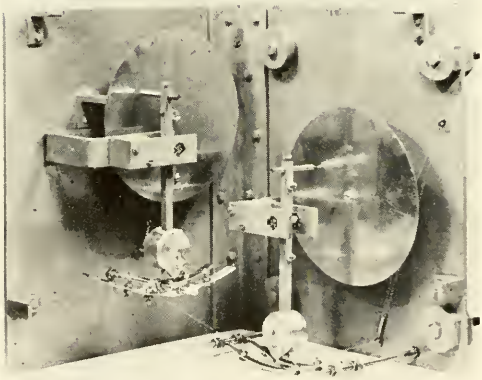
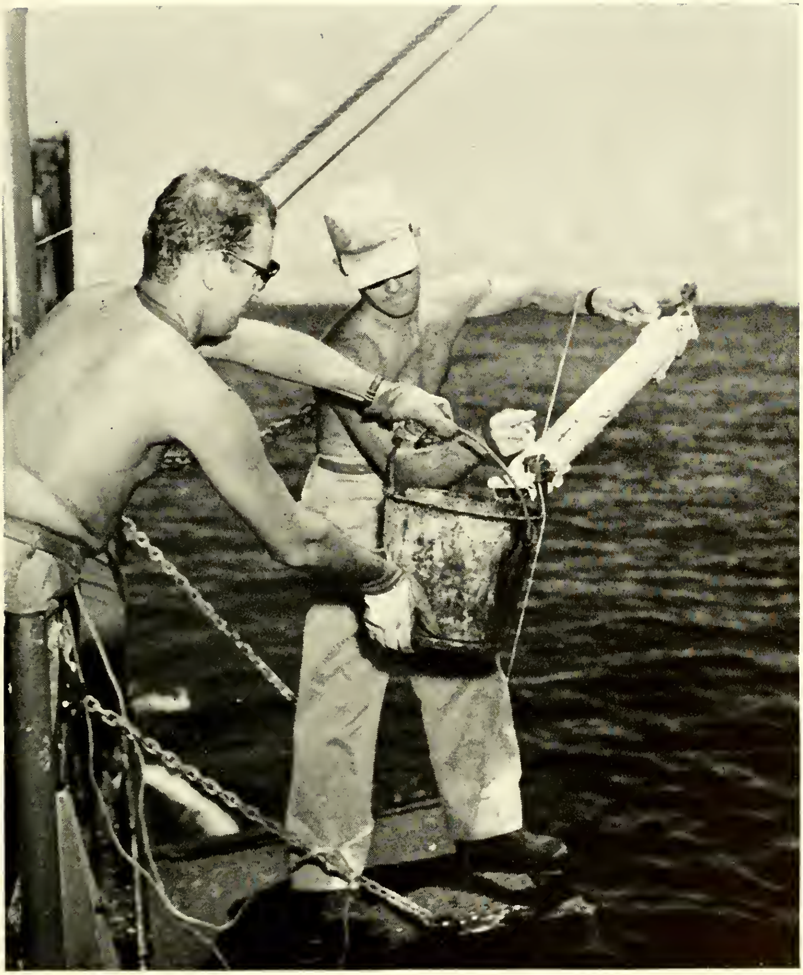


Plate 11



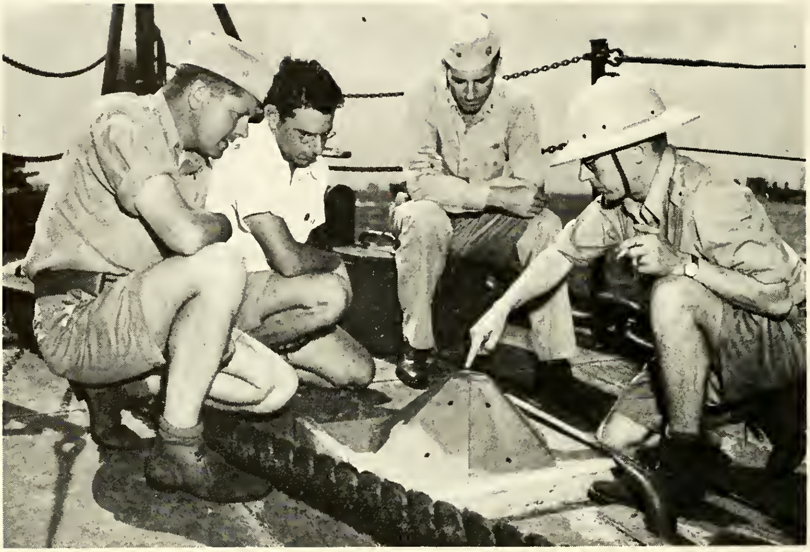
UPPER. Dr. C. W. Lampson and Captain A. E. Uehlinger inspect a ruptured-foil type gage for recording peak pressure in air. Ten aluminum foil disks of different size are visible. LOWER. Pendulum type inclinometer for automatically recording angles of roll and pitch of target ships. Records consist of scratches on the polished aluminum disks.

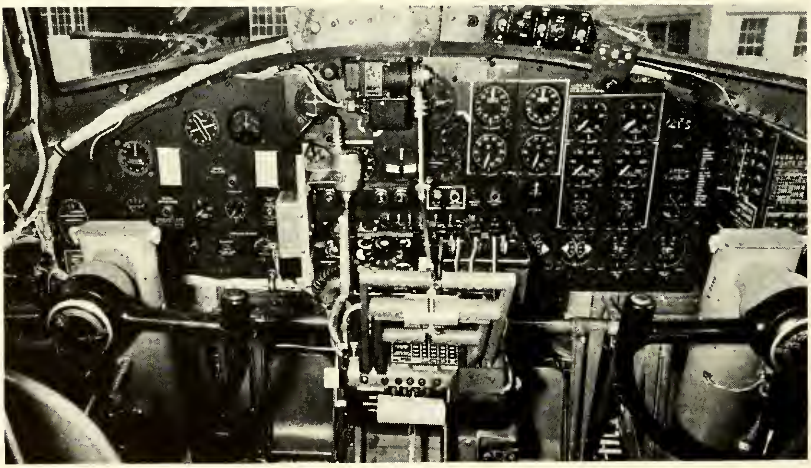
Plate 12



Members of Colonel S. L. Warren's Radioactivity Group sample the lagoon water by means of a Nansen bottle. Amounts of radioactivity in the water samples were determined with the aid of Geiger counters; the resulting data were entered on a "contour" chart showing the periphery of the "Geiger sour" area.

Plate 13





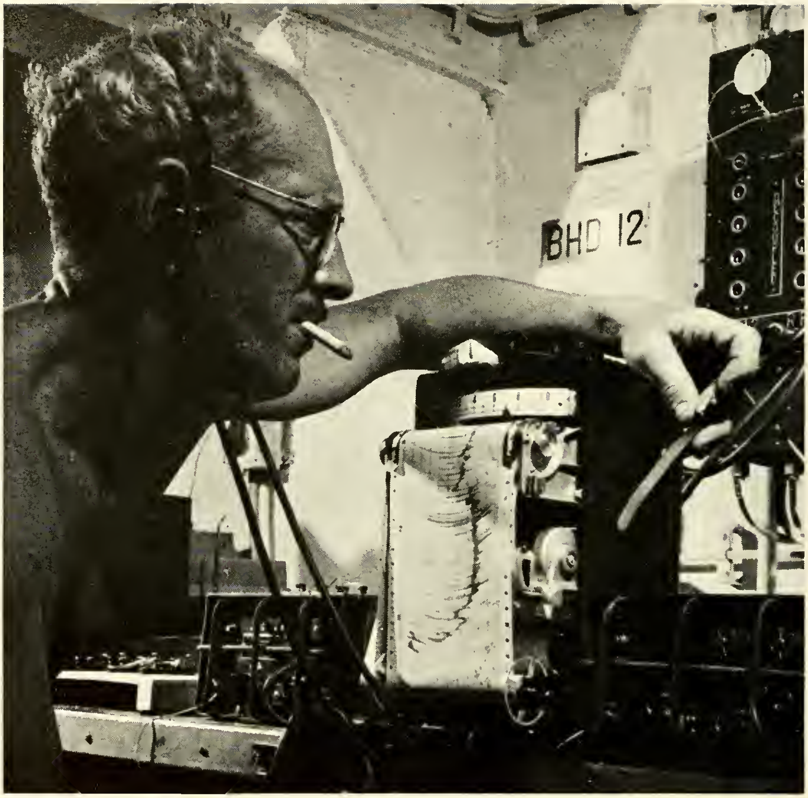
UPPER. Members of the BuOrd Instrumentation Group examine a deck-mounted pyramidal orientometer, a device for showing the direction from which the bomb's thermal radiation came. LOWER. Control panel of one of the B-17 Flying Fortress drones.

Plate 14

Final inspection and assembly of one of the thirty "turtles" specially designed by the BuOrd Instrumentation Group for recording pressure produced on the lagoon bottom by the huge waves generated by the B-Day underwater explosion. Pressure elements were of the Bourdon type, being actuated by water forced in by excessive external pressure. Water entered through a fine capillary serving as a protective frequency filter.

Ready to plant a turtle on the bottom of the lagoon. The turtle cases were made of very heavy steel to prevent their delicate contents from being flattened by the extremely intense underwater shock wave. For ease of recovery the turtles were attached to target vessels or special buoys by means of slack steel cables. However, several of the turtles placed near the center of the underwater explosion were never seen again.

Plate 15



In the Instrumentation Laboratory of the AG-76 AVERY ISLAND Mr. A. H. Waite, Jr., of the Radioactivity Measurement Section, checks the timing of an automatic pen-and-ink recorder. Such recorders were used on support ships to make permanent records of data gathered by automatic instruments on "hot" target ships. Several of the Geiger counters on the target ships were employed in such telemeter system; readings were broadcast automatically to recorders on support ships stationed several miles from Bikini Atoll. The permanent records obtained were available for immediate use, or for more detailed analysis at a later time. Such data were of especially great importance in evaluating Test B, the underwater explosion.

Plate 16

aged by fires. Of course, the A-Day bomb might be (and indeed was) detonated at an unexpected position, which would mean that some gages would find themselves nearer the detonation than had been expected while others would be unexpectedly far away; some gages, accordingly, would give readings so large as to be off-scale and others would read zero.

Other complications were that the target vessels, despite their special moorings, were continually shifting with the tide and wind. Pressure gages intended for the exposed side of a target vessel might find themselves actually on the shielded side. Then there was always the chance that the bomb itself would be abnormally weak and would produce only abnormally-low pressures.

IMPULSE

To a physicist, impulse is no evanescent whim; it is a prosaic but useful measure of cumulative push. It takes account of both the *intensity* of a push and the *duration* of the push, and is thus a compound concept. The intensity and the duration were both expected to be very great in the Bikini explosions. Engineers were undecided as to whether pressure, impulse, velocity, or acceleration data would be most useful in explaining damage; but all agreed that impulse was one of the important quantities to be studied if explosions and explosion-produced damage were to be fully understood.

Impulse can be computed directly from pressure-versus-time data.* It can also be measured by special gages which take account of intensity as well as duration of pressure. A number of such gages were constructed and placed at strategic locations on target vessels. No detailed description of these gages is necessary; many of them resemble some of the pressure gages described on the previous pages, but contain heavier, slower-moving pistons, better suited to taking a long view of things.

SHOCK-WAVE VELOCITY

Shock-wave is the name given to a pressure wave in its early, spectacular phase. To appreciate the spectacular phase, one must recall the relatively unspectacular behavior of most pressure waves. A typical pressure wave, such as the sound wave produced by banging a dishpan, leads a very dull life. It has no choice as to the velocity of spreading. It always spreads at exactly the same rate of roughly 1100 feet per second. This applies to faint sounds and moderately loud sounds, to low-pitched sounds and high-pitched sounds. And such

** It is well known that at moderate and great distances from an explosion, the overall impulse is zero. That is, the initial push is exactly balanced by the pull of the ensuing suction phase. Close to the Zeropoint, however, the push always exceeds the pull, and the overall impulse has a net value greater than zero.*

a wave avoids suddenness: like an ocean swell, the pressure increases gradually and then decreases gradually.

But a shock wave has a personality of its own. In the first place, its intensity is so great that it cannot be content with spreading at the usual velocity — the velocity of the fastest jet planes; it demands higher velocity, equal to that of the fastest bullets. The more intense the shock wave, the higher its velocity. Secondly, the pressure does not arrive at any given point gradually, but all at once. A building, tree, or ship may be enjoying an uneventful existence at one instant, but an instant later it may be reeling under the *full* impact by the pressure wave. There is absolutely no warning. The destructive effect is diabolically maximized.*

The most energetic explosions produce the most intense pressures and the most unusual shockwaves. The experts at Bikini therefore went to great lengths to measure the A-Day shockwave. Spearheading the attempts to measure shockwave velocity was a group of high-speed cameras. Some of these, located atop special towers on Amen Island, were operated automatically and were capable of taking over 500 individual pictures each second. By use of short exposure times, and, of course, long focal length lenses, Captain R. S. Quacken-

* *This suddenness, or vertical front phenomenon, is due to the tendency of the back part of the pressure wave to catch up with — and, so to speak, ride on the shoulders of — the front part. The result is of sledge-hammer severity.*

bush's expert photographers hoped to produce the world's finest portraits of mammoth shock waves.

Supplementing these cameras were other ingenious devices. Various kinds of shockwave detectors were placed at varying distances from the center of the target area. Some of the detectors were located on the target vessels; others floated on the water. Each detector was capable of sensing the passage of the shock wave and instantly dispatching a pre-arranged signal to monitoring apparatus located a few miles away. By such systems, shock-wave velocity could be determined much as the British air-raid wardens were able to clock the rate of approach of a German airplane heading for London. In the Bikini tests, however, the velocities would be many times greater, and the signaling had to be done without benefit of human hand.

OPTICAL RADIATION

The most spectacular result of Test A was to be the terrific output of optical radiation, including visible, ultraviolet, and infrared light. The intensity was expected to be greater than ever before produced on earth — except, of course, by the previously detonated atomic bombs.

The character of the light was not expected to be unusual. It has been known for many years that any very hot body tends to emit visible, ultraviolet, and infrared light. The atomic bomb, being extremely hot during the process of flying apart, thus conforms with this rule.

Measuring the total emission of light of all kinds was obviously desirable, since it would help to fix the total amount of energy released in the explosion. Also, it would help explain the flash burns to be produced on test animals and equipment. Measurements were arranged by Commander S. S. Ballard and his colleagues from the Naval Research Laboratory. This group, called the Radiometry Subgroup of the Bureau of Ordnance Instrumentation Group, had laid its plans long in advance. It had studied the optical radiation data obtained in the previous year's test at Alamogordo; it had estimated how greatly the absorption of Bikini atmosphere would differ from that of the dry atmosphere of Alamogordo, and had then designed and build instruments ideal for the job at hand. Principal reliance was placed on bolometers and thermocouples, very small devices which detect without discrimination light rays of all kinds and directions. The received light produces small electrical changes, which are amplified and ultimately cause small fountain pens to draw revealing curves on long sheets of graph paper.

Of principal interest to the spectroscopists was the spectral distribution, or the relative amounts of light of short and long wavelengths.* These men wondered,

* *In these optical studies the Naval Research Laboratory spectroscopists were assisted by spectroscopists from the Bureau of Ships, the Army Air Forces, and various private institutions.*

for example, how the intensity of ultraviolet light would compare with the intensity of visible light. Their wonderings led to the preparation of a number of different instruments, each designed to answer a specific question. Several broad spectral bands, for example, were to be compared by means of photocells or electric eyes. Each of these electric eyes was deliberately made color-blind to all but a single color — by the use of "rose-tinted glasses," or glasses of any other color desired. Thus each photocell was made ready to report the results in its own spectral zone. For more precise discrimination between different parts of the spectrum, spectrographs were used. These employed small prisms and gratings to separate more cleanly the different wavelengths; results were recorded on strips of photographic film.

High-speed techniques also were brought in. Commander Ballard knew that tremendous changes would occur in the emission of optical radiation during the first few instants after the detonation. The changes would occur hundreds of times too fast for the human eye to notice — even if the eye were not momentarily blinded. To catch these rapid changes, photocells were used. Their responses, free from any appreciable delay, were to be translated by means of cathode ray oscillographs into the usual end-products dear to the heart of scientists: accurate and permanent charts.

Size and rate of growth of the fireball came in for much attention. The creation of the atomic bomb had fascinated experts on thermodynamics who were asking themselves: When the explosion first occurs, which gets off to the fastest start: the pressure wave? the optical radiation? the nuclear radiation? or actual materials from the bomb? Satisfactory answers were nonexistent. Everyone agreed that at the instant of detonation, the bomb, or at least what had been the bomb, is extremely hot. Its temperature is perhaps of the order of a million degrees Centigrade. And everyone agreed that every bit of matter which has that temperature cannot fail to emit enormous quantities of optical radiation. (It is well known, for example, that doubling the temperature of a hot body causes it to emit *sixteen* times as much energy, so that the rate of emission of energy from a body raised to a million degrees must be staggering indeed.) But a tremendous complication at once sets in. The bulk of the energy is of very short wavelength, a wavelength which the atmosphere refuses to transmit. Thus a curious kind of leapfrog must be taking place: the short-wavelength energy starts outward, but before it has gone more than a few feet, it is absorbed by the surrounding air. The surrounding air, however, is so heated by having absorbed this energy that it becomes highly luminous and *itself* radiates energy. This energy fares little better than the previous generation and is in turn absorbed. So a sort of leapfrogging chain-reaction is set up, in which energy is being constantly absorbed and re-radiated. The velocity of light is well known; but who knows the velocity of such a halting process? The process cannot be imitated successfully in the laboratory; we have little to go on except estimates by thermodynamics experts — and close study of Test A at Bikini.

The rate of spreading of this optical radiation zone (rate of growth of the fireball) was to be measured principally by cameras. But no ordinary camera would do. Two special types, the O'Brien and the Bowen, were obtained. Each of these had microsecond resolution; that is, each could distinguish what happened from one millionth of a second to the next millionth. Each was set up several miles from the target area center; each was capable of charting the fireball's development from birth to old age, a total span of only one or two seconds.

The lowly human eye was used also. In order to escape temporary blindness, it had to be protected by dark goggles* or by the ingenious device called an Icaroscope. It was realized in advance that goggles could not be a perfect solution. Goggles satisfactory for the instant of greatest brightness would, of course, be too dark for the ensuing less-bright intervals. It

* *Most of the 6000 users of the special goggles found them too dark. This was due partly to the abnormally great extent to which light was absorbed in traveling for many miles just above the surface of the water; also it was due partly to the desire of the safety advisers to make doubly sure that no one would suffer any*

would be necessary to throw aside the goggles during this important transition stage.

A more versatile aid to the "obsolete" human eye was the Icaroscope. This device, invented during the war by Prof. Brian O'Brien of the University of Rochester, represents the first use of the optical analog of the automatic volume control commonly used in radio sets. In the Icaroscope, excess brilliance is eliminated by means of an ingenious use of phosphorescence. Phosphorescent images, not direct images, are viewed. And whereas objects of intermediate brightness appear little changed, over-brilliant objects are subdued to a comfortable brightness. During the war the Icaroscope permitted effortless visual detection of airplanes approaching directly "out of the sun." At Bikini, over fifty Icaroscopes were made ready for viewing the almost-unviewable fireball. A few of the Icaroscopes were scanned by motion-picture cameras instead of eyes.

NUCLEAR RADIATIONS

Nuclear radiations, almost unknown to the public prior to the obliteration of Hiroshima, are now well known. Thus, gamma rays are true rays or waves; they resemble X-rays, but can penetrate even a foot-

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eye injury. The goggles actually transmitted only about 0.003 percent of the light striking them; without doubt a transmission two to ten times greater would have been better under the particular conditions prevailing.

thick steel wall. Beta rays are particles. Specifically they are light-weight negatively-charged particles called electrons; they can scarcely penetrate a sheet of cardboard. Alpha rays are heavier particles and carry positive charges; they too have little penetrating power. Neutrons are uncharged particles; because of their lack of charge they are slippery, hard to stop. They can penetrate several feet of steel.

In preparing for A-Day, Colonel S. L. Warren and other experts of the Radioactivity Group focused their attention on a period of one minute. They knew that in the A-Day Test, where the bomb was to be detonated in the air, the great bulk of the materials producing nuclear radiations would be carried upward by the fireball and the mushroom. Only during the first minute would the nuclear radiations be of outstanding intensity.*

There was no mystery as to the source of the nuclear radiation. It was known that the fission products would be highly radioactive.† *Fission products,* of

** It was expected that on B-Day, when the bomb was set off underwater, the materials emitting nuclear radiations would be trapped in the water and would present a prolonged menace. Preparations for this more complicated situation are discussed in a later chapter.*

† *Fissionable materials themselves can, of course be injurious. The* Smyth Report *states that among materials which are radioactive or toxic are to be listed not only fission products but uranium and plutonium themselves; uranium, aside from its radioactive properties, is poisonous chemically, and plutonium is alpha-radioactive.*

course, is the blanket name given to the fragments formed when atoms of uranium or plutonium are split. The splitting, which occurs within a small fraction of a second after the atom captures a neutron, does not always give the same kinds of fragments. In fact, more than 100 kinds have been identified.* Among them are: nuclei of atoms of bromine, krypton, rubidium, strontium, ytterbium, columbium, molybdenum, antimony, telurium, iodine, xenon, cesium, barium, lanthanum. As the bomb detonates, *billions of billions* of such fragments are flung out.

To radiologists, the importance of these fission products lies in their instability. The products are not well-adjusted at the time of their birth, but go through tumultuous "nervous breakdowns"; their electrical charge is poorly matched to their weight. Readjustment usually takes the form of emitting gamma rays, electrons, or neutrons.

The principal questions asked by radiologists were: How rapidly do these readjustments come? How soon are they finished? Which type of radiation predominates? Of course, for any one kind of fission product the answers may usually be obtainable in the laboratory; but the fission products are such a motley mixture, such an ephemeral hodge-podge, that their cumu-

**A recent tabulation, presented in the Journal of the American Chemical Society for November 1946, lists 160 fission products (including isotopes).*

lative effects are very difficult to predict. Studies have been made, of course, of fission products produced in the piles operating at Oak Ridge and elsewhere. But those fission products are born of a different process; they result from fission produced by *slow* neutrons. Only when an atomic bomb explodes can the fission products of a *fast* neutron chain reaction be studied.

From the tactical point of view this question was important: How far out does the gamma radiation reach? It was well known that gamma radiation is absorbed by air; but definite answers were lacking as to just how many hundreds of yards of air were needed to protect exposed personnel. For neutrons, too, information on shielding by air was incomplete. With respect to both gamma and neutron radiations, more information was needed as to the protection afforded by steel walls. It was recognized that persons located below decks would be relatively protected, but the exact extent to which such protection really would save lives was not known.

Colonel Warren's group brought to Bikini more than 20,000 devices for measuring nuclear radiations. The commonest device used for measuring gamma radiation consisted merely of a small piece of unexposed photographic film wrapped so as to exclude all light. This device, called a badge, does its job silently and simply. When gamma rays strike the badge, they penetrate the wrapping and produce a slight change in the photographic emulsion. When the badge's message is to be read, the badge is placed in photographic developing solution, and the emulsion becomes darkened. The degree of darkening indicates the total amount of gamma radiation which struck the badge. Such badges were among the simplest and most reliable of all gages used at Bikini. Thousands were used for each of the two explosions. They were placed at innumerable positions topside on target vessels, below decks, and in the same compartments where test animals were stationed.*

Geiger counters were to be used to find the intensity of gamma radiation at any one moment. These counters are especially useful because they produce their answers at once — either by motion of a needle across a dial, or by producing a machine-gun noise in headphones. The marvel of the Geiger counter is that it can detect a single *photon,* or unit of gamma radiation. Heart of the counter is a crude electron tube, containing a central wire and a small quantity of gas; the wire is at critically high voltage, such that the slightest disturbance — even the slight disturbance produced by arrival of a single photon of gamma radiation — completely upsets the electrostatic regime and causes a violent discharge of current. Equilibrium is restored

* *Much operational use was made of such badges. They were carried continuously by persons working in contaminated areas where unsuspectedly large dosages of gamma radiation might be acquired. By developing and analyzing the badges, reliable answers could be found as to whether or not over-exposure had occurred. Fortunately, the answers were always in the negative.*

almost instantly, and the counter is ready to detect the next photon. Detecting and even counting these discharges is simple enough. Many different varieties of Geiger counters were prepared. Some were easily carried in the hand, for making quick spot checks. Others were equipped to operate for long periods of time without attention, recording their experiences on graph paper or even radioing their findings to men and recording instruments located a few miles away. A few were equipped to operate underwater. Some were mounted in drone boats, a few carried in planes.

Preparations were made for measuring alpha, beta, and neutron radiations also. Various standard types of instruments were used; far fewer were required than for gamma radiation.

TEST ANIMALS

Noah would have felt at home on the BURLESON. But he would have been surprised at the selection of animals which Captain R. H. Draeger (Navy Medical Corps) brought. There were 200 pigs, 60 guinea pigs, 204 goats, 5000 rats, and 200 mice.

There was nothing haphazard in this choice. The animals selected must be capable of keeping in good health despite weeks spent on shipboard. Tropical weather must not wilt them. They must be amenable to remaining for days in confined quarters and completely unattended. More important they must be of types already carefully studied; it would be necessary to translate their reactions into reactions of men.

Pigs were particularly valuable since their skin and short hair are comparable to man's. Goats were useful because their weight is comparable to man's and the quantity of their body fluid is sufficient for extensive laboratory analysis. Rats, time-honored experimental animals of radiology, were a logical choice since so much is known about their response to radiation and the correlation of their responses with man's.

Some of the goats taken along were selected for their psychoneurotic tendencies. Psychologists thought that the severe explosion phenomena might change these tendencies.

The mice were chosen from special strains showing especially great likelihood of developing cancer, or especially small likelihood. Here too it was hoped that some interesting change would be produced, either in these mice themselves or in their progeny.

No dogs were included. During the early planning of the operation many letters were received from the public urging that dogs be excluded.*

Surprising though it may seem, the main purpose of placing test animals on the target vessels was *not* to find what percentage of the ships' crews would be injured or killed. That information could be obtained without using test animals. It could be obtained by

** Over 50 percent of the letters of protest received from the public condemned the use of animals. A smaller percentage ex-*

instruments and calculations. Pressure gages, for example, would provide accurate knowledge of pressures produced. And previous history, such as that of Londoners exposed to German bombing attacks, had already shown clearly what pressures would do to men. It was well known that sudden pressures of one hundred pounds per square inch could kill a man outright. It was known that pressures of only five pounds per square inch could throw a man so vigorously, that if his head struck a hard surface, he might be killed. For gamma radiation the situation was similar. Gages would show the intensity of the radiation, and previous experience in laboratories would show how to evaluate the data in terms of injury to men.

The real purposes of using test animals were these: (1) to show the types of symptoms produced by the explosions; (2) to provide experience in cataloging injuries and detecting the onset of slowly-developing injuries; (3) to provide experience in treating injuries; and (4) to reveal any new kinds of effects. The injuries of principal interest were, of course, those caused by nuclear radiations. Such injuries were found at Hiroshima and Nagasaki, but the significant facts had often been lost in the welter of confusing circumstances such as fires, floods, starvation, exposure, lack

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pressed fear of a widespread calamity. One writer was very grieved that the A-Day program was to come on a Sunday, intended to be a day of quiet and prayer; he expressed great relief when he was informed that Sunday in U. S. A. was actually Monday at Bikini.

of medical care. Little success had been encountered in trying to reconstruct the relationship between injury and cause of injury. It was to fill such gaps that test animals were taken to Bikini. However, the number taken was kept to a minimum.

Captain Draeger and his Executive Officer, Captain Shields Warren (Navy Medical Corps) were well supported in their work. Starting with an important planning conference held in early January 1946, at the Naval Medical Research Institution at Bethesda, Md., full cooperation by many agencies was obtained. These principal Army and Navy medical research agencies helped: Army Chemical Warfare Service (including the Biological Warfare Division), Army Medical Corps, Navy Bureau of Medicine and Surgery, Naval Medical Research Institute. Also cooperating were the National Institute of Health of the United States Public Health Service, the United States Department of Agriculture, the National Cancer Institute, the United States Geological Survey, and various universities and private research agencies.

The BURLESON began taking aboard animals at the end of May 1946, in San Francisco. The special accommodations provided for the animals were found to be very satisfactory. The ship began its westward trip on June 1; she started long after the other vessels, and made a fast run. The object, of course, was to have the animals in the best possible condition at the time of the first Test.

Two weeks before Test A, the BURLESON passed through Enyu Channel and joined the 140-odd support ships already anchored at the northeast corner of the lagoon.

6. BIKINI OVERTURE

The SUMNER and the BOWDITCH were among the first of the ships to reach Bikini. In late January 1946, the Chief of Naval Operations arranged for these ships to proceed to Bikini to make needed surveys and oceanographic studies. SUMNER did the bulk of the hydrographic surveying. Her work was especially urgent because the only available hydrographic charts of Bikini were Japanese and were quite inadequate. SUMNER and assisting ships made some use of acoustical bottom scanners, but principal reliance was placed on wire-drag methods.

The survey was finished in April, and the data were flown to the Navy's Hydrographic Office in Washington, D. C., where the new charts were printed. Figure 3 is a simplified chart showing the form of the 26-island Atoll. The earlier names of the Atoll's 26 islands were difficult to spell and would have been almost impossible to handle in dispatches. Accordingly a set of simple code names was adopted by the Task Force. The two groups of names are as follows:

Earlier Name	*Code Name*
Airukiiji	Arji
Airukiraru	Airy

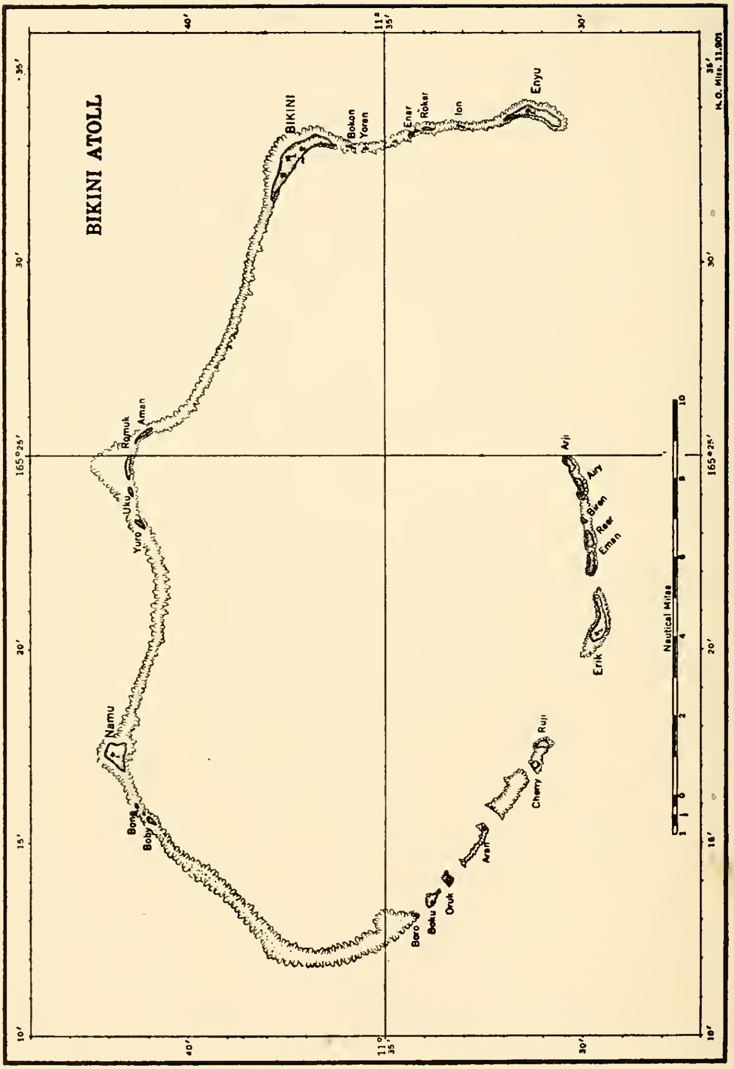


Fig. 3. Bikini Atoll.

Aomoen	Amen
Arriikan	Aran
Bigiren	Biren
Bikini	Bikini
Bokoaetokutoku	Boku
Bokobyaadaa	Boby
Bokonejien	Bone
Bokonfuaaku	Bokon
Bokororyuru	Boro
Chieerete	Cherry
Eniairo	Enar
Eniirikku	Erik
Eninman	Eman*
Enyu	Enyu
Ionchebi	Ion
Namu	Namu
Ourukaen	Oruk
Reere	Reer
Rochikarai	Rokar
Romurikku	Romuk
Rukeji	Ruji
Uorikku	Uku
Yomyaran	Yoran
Yurochi	Yuro

BOWDITCH, which arrived at Bikini on March 10, 1946, gave valuable assistance to the SUMNER.† But BOWDITCH'S main job was making ocean-

* *This was later changed to "Prayer" to avoid confusion with "Amen."*

† *The BOWDITCH was built in Copenhagen over 30 years ago. She still retains her promenade deck, square portholes, and broad staircases. She was easily recognized by her trailing column of black smoke.*

ographic, biological, and geological surveys of the atoll. Aboard her were wave motion experts, icthyologists, botanists, zoologists, and geologists drawn from the Woods Hole Oceanographic Institution, the University of California's Scripps Institution of Oceanography, the Smithsonian Institution, the University of Michigan, the U. S. Geological Survey, the U. S. Department of the Interior's Fish and Wildlife Service, and the Army and Navy. These men, led by Lieutenant Commander C. A. Barnes of the U. S. Coast Guard, were the first scientists to reach Bikini, and they were among the last to leave. Their most urgent job was studying the lagoon currents to find out what might happen after the B-Day explosion, which would certainly disperse enormous quantities of radioactive materials in the water. Prompt re-entry into the target area would depend largely on accurate knowledge of these previously-uncharted currents.

The BOWDITCH'S scientists also took censuses of populations of fishes, corals, and other animals, to permit later evaluation of the effects of the bombs on animal life of the atoll. Fish were caught with hook, net, and seine. In some instances, the fish were poisoned with rotenone and picked up dead. To increase the significance of the censuses, similar censuses were taken at unaffected "control" atolls, Rongerik and Rongelap, 125 miles upwind, and also at Eniwetok, 200 miles downwind. Botanists made systematic surveys of plant life, and geologists gave the atoll the most thorough going-over ever accorded one of these billion ton piles of skeletal remains.

The order to evacuate the natives came from the Navy Military Government Officer in February, when choice of Bikini as the test site became final. The Bikinians, convinced that the Tests would be a contribution to world peace, indicated their willingness to evacuate.* Their decision was reached at a meeting of the Atoll Council. Nine of the eleven *alaps* (family heads) named Rongerik Atoll, 128 miles to the East, as their first choice for resettlement. Lajrwe, Paramount Chief of Rongerik, concurred in this proposal. The trip was made on March 7, 1946, on LST 1108. Although much effort was spent to establish the Bikinians comfortably on Rongerik, some dissatisfaction and nostalgia have been apparent. Whether they will remain there is uncertain; radioactivity at Bikini renders their return there unsafe at present.

Japanese mines had to be cleared from Bikini Lagoon before the support and target fleets arrived. Thirty-five mines had been located and removed dur-

* *Juda, Magistrate of Bikini Atoll, commonly called King of Bikini, witnessed one of the Tests, but the other 161 inhabitants obtained only second-hand accounts. He was flown back to Bikini the day preceding B-Day, before final approval for such a visit had been obtained from the Joint Chiefs of Staff. He was received aboard the flagship MT. McKINLEY amid much embarrassment. The situation was saved by a quick interchange of radiograms with the office of the Joint Chiefs of Staff in Washington, D. C. Word came back to Bikini that the Task Force Commander might "use his judgment" in the matter.*

ing September and October of 1945 by Task Unit 96.38.1 under the Commander of the Marshall-Gilberts Area. Five more mines were removed during March of 1946 by Commander, Minecraft Pacific, Task Unit 18.11.

Coral heads were another menace to navigation inside the Lagoon. They consisted of great underwater obstructions rising nearly 200 feet above the lagoon floor. Many of them extended up to the level of the lagoon surface. Composed of corals and also deposits made by the calcerous algae, they were solid enough to damage any ships which might collide with them. Some were in positions to interfere with the mooring of target vessels or to impede the submerging of the target submarines. Accordingly, the tops of these coral heads were removed by dynamiting. Over 100 tons of dynamite were used.

Much construction work was required on Bikini Atoll. Principal structures built were the following:

12	75-ft. steel towers for mounting cameras and other technical equipment. (In view of high winds prevailing, these towers were constructed in horizontal position and then hoisted into vertical position.)
5	25-ft. wood towers
12	20 ft. x 20 ft. steel huts
5	Seismograph huts
5	"Dead-man" moorings for Test C
6	Photography beacons, for aerial photography fixes

1	Club (20 ft. x 200 ft.) for officers and civilians
1	Club (16 ft. x 300 ft.) for enlisted men
5	Concrete basketball courts
10	Volley ball courts
4	Softball diamonds
1	Trap-shooting range
1	Concrete athletic court (100 ft. x 100 ft.)
26	Dressing huts
1	Water distillation and distributing system
1	Shore patrol and dispensary building
3	Life-guard platforms
1	Seaplane landing ramp
2	Swim floats
7	Pontoon causeways
1	Air-coordination station
3	Construction battalion shops
1	Sonobuoy work shop
10	Wave-height measurement piles
14	Shallow-water moorings for evacuation barges and other small craft
2	Radio beacons
5	25-man camps
1	Aerological station

This construction was done by the 53rd Naval Construction Battalion. The first group of the Construction Battalion to arrive at Bikini was a survey party which arrived on March 11. By March 20 the entire Battalion had arrived.

To reduce the insect nuisance, Bikini and Enyu Islands were sprayed every few weeks with DDT;

Amen and Erik were sprayed once. These precautions proved effective.

Preparing moorings was a large job. The mooring positions had been specified several weeks in advance, in Washington, D. C.; plans called for mooring bows and sterns of the central target ships to prevent excessive shifting with tide and wind.*

FORCE ORGANIZATION

Technical and scientific preparations were nearly complete as A-Day approached. But the success of that day was to depend fully as much on the Force Organization as on the Staff and Technical Organization.

The Force Organization was responsible for operations. After policy questions had been decided by the staff organization and after the technical requirements had been decided by the technical men, it became the responsibility of the Force Organization to execute the necessary action in the field.

The Force Organization which had been adopted by Admiral Blandy was designed especially to meet the unusual requirements of the Operation. Eight separate Task Groups were created.

**A typical mooring consisted of a buoy, a riser chain, a clump, three 10-ton anchors, and three anchor chains. The clump was a 10-ton concrete block resting on the bottom of the lagoon. It was attached to the anchors by means of 500-ft. chains. The riser chain connecting the buoy and the clump was made as short as feasible, to limit the swing of the attached target vessel.*

Task Group 1.1, the Technical Group, was commanded by Rear Admiral W. S. Parsons, who was also Deputy Task Force Commander for Technical Direction. The group included seven large laboratory ships, several radio-controlled drone boats, and LSM-60, which was the ship from which the B-Day bomb was to be suspended.

Task Group 1.2, the Target Vessel Group, was commanded by Rear Admiral F. G. Fahrion, who had also served as Commander of the Advance Echelon and Commander of all the Naval Task Groups until the Task Force Commander's arrival at Pearl Harbor. From his Task Group flagship FALL RIVER, Admiral Fahrion directed all operations of the 93 target vessels, including mooring them. (These vessels are listed in Appendix 9.)

Task Group 1.3, the Transport Group, was commanded by Captain W. P. Davis (Navy), who was responsible for the press ship APPALACHIAN, the observer ships BLUE RIDGE and PANAMINT, and eleven other large transport ships which were to quarter and mess the target ships' crews after those ships had been evacuated.

Task Group 1.4, the Army Ground Group, was led by Colonel J. D. Frederick. It was responsible for all operational activities by the Army Ground Group. Included were units drawn from the Signal Corps, Ordnance Department, Chemical Corps, Quartermaster Corps, and Army Air Forces. Principal activity was exposing as many types of Army equipment as possible to the explosions and determining the damage produced.

Task Group 1.5, the Army Air Group, was commanded by Brigadier General R. M. Ramey. It was responsible for all operations by Army planes. Its Air Transport Unit, comprising ten C-54's each capable of carrying 54 persons, flew thousands of tons of Crossroads personnel and freight between Kwajalein and the United States. Its Tactical Operations Unit, comprising 13 B-29's, flew the bomb-carrying plane used in Test A and also flew weather and radiological reconnaissance planes. Other units operated photographic planes, scientific instrumentation planes, and radio, press, and observer planes. The Drone Unit was unique in aviation history; it successfully operated 6 B-17 Flying Fortresses as drones. With no one aboard, these great planes were radio-guided through their prescribed flights across the target area, a unique and impressive feat.*

**A number of Army Air Forces officials believe that the drone-plane program undertaken for Crossroads advanced the science of drone-plane operations by a year or more. To be sure, a few war weary B-17's had been flown without crews during the latter part of the recent war, but they and their cargoes of explosives were deliberately crash-landed. Also, a few B-17's had been landed by remote control; but pilots were aboard, ready to take over control in case of trouble. Operation Crossroads was the first operation in which take-off, flight, and landing were accomplished with no one aboard. The feat was an impressive one; many experts had thought it could never be accomplished with planes of this size.*

Their photographic and air-sampling missions were accomplished without accident to any of the participating Fortresses.*

Task Group 1.6, the Navy Air Group, was commanded by Rear Admiral C. A. F. Sprague. This group added to aviation history by perfecting the radio-control of drone planes catapulted from an aircraft carrier.† Such planes were used for photography and for collecting air samples. The Group also operated four helicopters, fifteen PBM patrol planes, and several TBM avengers for use in guiding drone boats. Activities were based principally on the carriers SHANGRI-LA and SAIDOR.

Task Group 1.7, the Surface Patrol Group, was commanded by Captain E. N. Parker (Navy). It was to play an especially large part in the radiological safety operations immediately following the underwater explosion, Test B.

Task Group 1.8, commanded by Captain G. H. Lyttle (Navy), was responsible for many services, in-

* *Closest approach to an accident occurred just after the B-Day explosion, when one of the B-17 drones, returning to its Eniwetok base overran the runway and came to rest on the beach. The plane had been flying directly above the Zeropoint when the explosion occurred, and its brakes had been damaged. Fortunately, overrunning the runway did no damage of any significance.*

† *The drone planes, F6F Hellcats, were not landed on the carrier but on an airfield at Roi, an island of Kwajalein Atoll. Shortly before the A-Day explosion one of the drones went out of control and crashed.*

cluding repair, fueling, water, mail, provisions, recreation, hospitalization, and evacuation.

Lines of organization were pleasantly invisible at Bikini. Officers and enlisted men, scientists, and observers, became a part of the tropical scene.

Shrill pipes called the men early each morning. Breakfasts were varied and substantial. Plans of the day were posted. Climbing from their steel-walled living quarters to the clean gray decks, the men gave first attention to the weather. Fortunately, fair weather and cooling breezes usually prevailed. Tuna and barracuda could occasionally be seen circling the ship.

The clutter of small boats flanking each ship came to life. Coxswains and their crews climbed out along booms extending over the water; they descended by rope ladders into the yawning boats bobbing up and down on the waves. They warmed up the engines, received megaphoned orders from the officer-of-the-deck, cast off, and then picked up their loads of scientists, technicians, and inspectors.

By 9:00 a.m. thousands of men had been deposited on the target vessels. They installed apparatus, tested it, and adjusted it. They put animals aboard, placed them in their cages, filled their reservoirs of food and water. They hoisted trucks, airplane sections, machine guns and field artillery aboard and secured them to the decks with steel cables running through eye-bolts. Boxes of pyrotechnics, canned goods, and medical supplies were taken aboard, made fast, and clearly labeled.

Meanwhile ships' engineers and their assistants were shutting down machinery and getting ready to close all watertight compartments. When the day of the test should finally arrive.

Throughout this scene of apparent confusion photographers and inspectors made their way, interminably photographing everything of interest and taking voluminous notes on ready-made forms. No reliance was to be placed on memory. The aim in the tests was not merely success or failure, but accurately-inscribed data sheets by the ton which could be referred to with confidence in the future.

Meanwhile force and staff conferences were being held on the MT. McKINLEY and good progress was reported.* Press conferences were held on the port deck of the APPALACHIAN.†

Men lucky enough to receive liberty picked up their swimming trunks, piled into LCVP's or whale boats and made for Bikini beach a few miles to the north. They spent the afternoons swimming, playing baseball,

* *It is not surprising that scientific and operational groups occasionally found themselves on opposing sides of discussions. Technical men showed no embarrassment in proposing whatever changes of plans would permit gathering better data. But operations men, anxious to avoid last-minute complications, favored standing pat. Because the Operation was basically a technical one, the technical men usually had their way.*

† *Dr. R. A. Sawyer, Technical Director, brought with him to one of the press conferences Mr. R. S. Warner, Jr., Los Alamos bomb expert. He introduced Mr. Warner as "the man who will tell you almost anything about the bomb — except what you want to know."*

drinking beer and soft drinks. In the evenings they attended motion picture shows on deck.* Recreation was made as pleasant as possible.

Rehearsals and weather dominated discussions during the last few days before A-Day. Many informal rehearsals were carried out by the various groups separately, and there was one full-dress rehearsal. This was held on Queen Day, June 24, and was completed with success.

The importance of weather was far greater than might be expected. Naturally, clear skies were desired by observers and photographers. Good visibility even from an altitude of five or six miles was needed by the bombing plane; no mistake could be tolerated in its identifying of the brightly-painted Zeropoint ship, NEVADA. High winds might have interfered with bombing accuracy and drone plane operation; unsteady winds might have permitted the radioactive materials in the air to be swept back over the support ships. Even though the winds might be steady at low altitudes, a counter current at high altitudes might have been disastrous to the support ships. But perhaps the most stringent requirement was that good weather be *predictable 24 hours in advance.* Only on the basis of firm advance prediction could the great A-Day program be gotten underway.

* *For the 42,000 men of the Task Force, daily requirements included 70,000 candy bars, 40,000 pounds of meat, 89,000 pounds of vegetables, 4,000 pounds of coffee, 38,000 pounds of fruit.*

Early in the morning of June 30 the weather experts made a prediction of fair weather and favorable winds for the following day, which was to be A-Day. The word was flashed to all ships and land stations, and to the entire world. Scientists gave their instruments a final tuning up, test animals were placed at their proper locations, target vessels were closed and the crews were taken off.

By dusk the evacuation of the lagoon was well underway. For hours the support ships had been filing silently southward, out into the open sea. No longer was the lagoon filled with twinkling lights and sputtering small boats. The target vessels lay deserted, a dark cluster in front of the thin dark line of abandoned beaches. For several of the ships, the sun had set for the last time.

7. TEST A: EXPLOSION IN AIR

The Test-A bomb exploded at exactly 34 seconds after 9:00 a.m. on July 1, 1946, Bikini local time, or approximately 5:01 p.m. June 30, 1946, Eastern Standard Time.

The bomb had left Kwajalein at 5:55 a.m., aboard the B-29 *Dave's Dream,* Aircraft No. 44-27354. It had been loaded on the previous day. At the originally scheduled take-off time, 5.34 a.m., the bomber was standing ready and waiting. But uncertain weather caused a short delay; the go-ahead signal was not radioed from the MT. McKINLEY until 5:40. Three minutes later the plane taxied towards the take-off position at the western end of the runway. The take-off itself was uneventful.*

Climbing slowly, the bombing plane held a northwesterly course. It reached bombing altitude over

* *Those who climbed aboard the plane were: Maj. W. P. Swancutt, Airplane Commander; Brig. Gen. R. M. Ramey, Task Group 1.5 Commander; Col. W. J. Blanchard, Air Attack Commander; Capt. W. C. Harrison, Jr. (Army), Co-Pilot; Maj. H. H. Wood, Bombardier; Col. J. R. Sutherland, Bomb Commander; Ens. D. L. Anderson, Weaponeer; Mr. L. D. Smith, Weaponeer; Capt. Paul Chenchar, Jr. (Army), Radar Observer; Maj. W. B. Adams, Navigator; Lt. R. M. Glenn (Army), Flight Engineer; Corp. R. M. Modlin, Scanner; Corp. H. B. Lyons, Scanner; Tech.*

Wotho Atoll, and continued on until 8:03 a.m., when it arrived over Bikini Atoll. Its first practice run over the target was made to check wind velocity figures received by radio from the aerological group.

The final practice run, a full-rehearsal run, began at 8:20 a.m. A radar beacon at Bikini was picked up from a distance of 50 miles and was used to time the approach and maintain the desired course of 45 degrees true. The Bomb Commander and his two weaponeers made last minute adjustments to bomb and bombsight. A flashing lamp on the NEVADA came into view; NEVADA's high-visibility paint was clearly identified. The simulated practice drop was made at 8:31 a.m.

The final run began at 8:50 a.m., from a distance of more than 50 miles. Course and altitude were held constant. Visibility was excellent. Within a few seconds of 9:00 a.m. the bomb was released and the bombardier called "Bomb away, bomb away!"

Bomb bay doors were then closed, and the plane made a 150 degree level turn to the left. It made a shallow dive, losing 1000 feet altitude while increasing speed of get-away.

Sgt. J. W. Cothran, Radio Operator. Major Swancutt's crew had been chosen for the job after long training at the bombing ranges at Alamogordo, N. M.; Albuquerque, N. M.; and over Erik Island of Bikini Atoll. His crew was winner in a strenuous competition among many other outstanding crews. His plane was named after Capt. David Semple, Army bombing expert and leading bombardier in the early competition, who was killed in a B-29 crash in New Mexico before the move to Kwajalein.

During the first few seconds of the bomb's descent, the bomb's course was almost parallel to that of the plane itself, and its velocity too was essentially the same (roughly 300 miles per hour). The downward velocity of the bomb increased rapidly at this point.

The target, enjoying its last few seconds of normal existence, was the most gigantic test target ever assembled. Enclosing it was the deserted circle of islands and reefs; beached on Bikini were: one LST, two LCI's, four LCT's, five LCM's, and 6 LCVP's a total of eighteen landing craft. Anchored on the surface of the lagoon were two great PB2Y-5E Coronado seaplanes.

But the heart of the target area was the great fleet of vessels clustering about the NEVADA.* Nearest the NEVADA were the Japanese battleship NAGATO, the Japanese cruiser SAKAWA, the carrier INDEPENDENCE, the cruiser PENSACOLA, the submarine SKATE, the destroyer HUGHES, the concrete oil barge YO-160, and the small LCM-1. The full list of target vessels is given in Appendix 9.

Just outside the Lagoon, 42,000 men lined the rails of their ships and waited. Nearest support ships, ten

** Ships located very near the bull's-eye, and ships almost directly upwind from the bull's-eye, carried light loads of fuel (10 to 33 percent) to avoid fires which might spread and envelop the very closely-spaced ships. The remainder of the ships carried large fuel loads ranging from 50 to 95 percent of capacity. Ammunition loads were arranged in general accord with this same scheme. The loading as well as the spacing was approved by the Joint Chiefs of Staff.*

to fifteen miles away were: APPLING, ARTEMIS, AVERY ISLAND, BARTON, BEGOR, BURLESON, CUMBERLAND SOUND, HAVEN, HENRICO, LAFFEY, MT. McKINLEY, O'BRIEN, WALKE, WHARTON, WHITING. Other ships were fifteen to twenty-five miles away.

Waiting aloft were airplanes, manned and unmanned. Nearest manned planes were *Dave's Dream* and the F-13 photographic plane, *Eggleston Eight*. Nearest drone planes were three Navy F6F drone planes and one Army B-17 drone plane, all at twenty miles. There were three more Army B-17 drone planes at thirty miles.

The bomb never reached sea level. When still several hundred feet in the air, its special fuze came into action and set the uncontrolled nuclear chain reaction in motion. Generation after generation of fast neutrons sprang to life, born out of the atoms undergoing fission. Each generation was much larger than its predecessor. The last few generations, born only a few millionths of a second after their remote ancestors, were prodigious. The number of neutrons at work exceeded the population of the earth.

An amount of matter no heavier than a dime was annihilated. But the energy release was enormous, being roughly 1,000,000,000,000,000,000,000 ergs. This was equivalent to the detonation of approximately 20,000 tons of TNT, a weight too great to be carried even by the world's largest fleets of giant bombers.

This huge quantity of free energy could not be tolerated by the bomb case. The outrush of energy was so violent that it would be inaccurate to say that the bomb case cracked or even melted. It simply sprang outwards in all directions as though it were a gas; individual atoms shot outward with speeds far exceeding the velocity of sound. Each atom started its trip instantaneously, and without regard to previous physical condition. It was literally "every atom for itself" in the chaotic rush from the intolerable concentration of energy.

Atoms were not alone in their outward flight. Neutrons, beta particles, and protons joined the rush. Mingled with them were the highly radioactive fission products.

Electromagnetic radiations, too, joined the surge. Gamma rays of extremely great intensity started outward with the velocity of light, and ultraviolet light, visible light, and infrared light followed suit. These wave-like radiations tended to outrace the atoms and nuclear fragments.

It was the visible light which gave the observers their first indication that the explosion had taken place. This light, accompanied by invisible ultraviolet and infrared radiation, sped onward, and even at distances as great as the moon it would have been clearly visible.

Let us slow down the events of the first few seconds after the detonation and examine each phenomenon closely in the light of all information now available and releasable. What the eye took in was relatively inconsequential, but the complete story revealed by the phalanx of instruments is a tremendous one. To analyze it fully will require hundreds or even thousands of man-years of effort by army and navy engineers.

For simplicity, we shall use *Zeropoint* hereafter to indicate the *actual* position of the bomb at the instant of detonation (Mike Hour); *projected Zeropoint* refers to the point on the Lagoon surface directly beneath the Zeropoint.

SHOCK-WAVE VELOCITY

From the detonating bomb the spherical shock wave in air spread rapidly. High speed cameras clocked its expansion. Very close to the bomb the shock wave velocity was extremely great, undoubtedly more than three miles per second, or 10,000 miles per hour. No bullet or rocket has ever approached this speed.

Even by the end of the first tenth of a second the shock wave had slowed considerably. Before one second had passed, it struck the water and forced the surface down several feet throughout a wide area. The shock wave reflected from the surface of the water now joined the direct wave; the merged wave then expanded at very high speed, whipping the surface of the water into shimmering fury. Many of the air-borne cameras made excellent records of the line of demarcation between agitated water and water not yet swept. The shock wave buffeted every ship of the target array and, still traveling at velocity greater than that of sound, continued its outward sweep.

After traveling three miles, the shock wave had lost much of its original character. Its hammer-blow quality was less pronounced, and it took on the character of a sudden violent gust of wind. The automatically-operated motion picture cameras on Bikini showed the palm trees shake vigorously as the invisible wave shot past.

After roughly fifty seconds the wave reached the support ships, located ten or more miles from the Zeropoint. But at this distance it was no longer a shock wave; it was a mere pressure wave. The wave front was no longer "square"; the velocity had subsided to that of sound, 1140 feet per second. This fully-tamed wave produced in the ears of observers only a dull, low-pitched thud.

The shock wave had quitted the lagoon; but thousands of instruments bore witness to its passage, and five ships were sinking.

PRESSURE

Within five seconds an excellent, indelible record was obtained of peak pressure, the most important property of the shock wave. The majority of the gages had performed well. The simplest ones operated especially well during the entire performance of the invisible shock wave.

Hundreds of gages were recovered within 48 hours. Recovering the gages from the GILLIAM was particularly dramatic. GILLIAM was the ship nearest the Zeropoint; in fact she was the only ship within 1000 ft. of the projected Zeropoint. She took a terrific beating, and sank almost immediately. Pressure experts were most anxious to find what the pressure had been at this key location; they wanted to know just what constituted a fatal blow. Divers were put to work quickly. They were briefed carefully as to just what to look for, or rather grope for. They went down, moving about with great difficulty through the almost formless wreckage. Twice they came up to the surface to report failure, and twice they were briefed further and sent down to try again. The third attempt succeeded. They located the gages and brought them to the surface. Beaming scientists carried the gages back to the laboratory ship KENNETH WHITING, cleansed them, and then strove to interpret their messages. No one had expected the bomb to explode close to GILLIAM; accordingly the gages placed aboard her were not of a type intended for measuring very high pressures. Many of them had gone far offscale. Careful study was needed before the readings could be interpreted reliably.

Pressure readings from all types of gages were now compiled, and elaborate graphs prepared. To the gratification of the experts, the graphs jibed closely with expectations. Both the height and shape of the plotted curves agreed well with predictions made months before by scientists from the Los Alamos Laboratory and from the Navy's Bureau of Ordnance. The accuracy, too, was satisfying. Although individual values often appeared out of line by 20 or 40 percent, when the readings of all gages at a given range had been averaged, a composite value of high accuracy resulted.

Many pressure values considerably greater than 100 pounds per square inch were successfully recorded. They were obtained by gages located at or just above the surface of the water some distance from the projected Zeropoint. Unfortunately, there was no gage located exactly at the projected Zeropoint; but estimates indicate that the pressure there was extremely great—expressible in hundreds or thousands of pounds per square inch. At greater distances, pressure values were, of course, smaller; at ranges of 2000 to 3000 yards, for example, the pressure was well below ten pounds per square inch. The radiosonde-type pressure gages parachuted from planes at ranges of six or eight miles performed well. Their radioed messages were received, recorded, and analyzed. Their pressure values, amounting to only a small fraction of a pound per square inch, were in excellent agreement with one another.

Pressures inside gun turrets and ship compartments were small, seldom exceeding a few pounds per square inch. The data obtained were sufficiently extensive to form a firm basis for determining where crew members would have been safe from the blast, and where additional protection would have been needed to insure safety.

There were, of course, many failures among the thousands of pressure gages used. Some of those which were to be started by radio were started too late as a result of a timing signal failure.* Others operated badly as a result of imperfect adjustment of the gages themselves or of "black box" starting mechanisms. Some gages found themselves unexpectedly close to the Zeropoint and gave undecipherable off-scale readings; others were unexpectedly far from the Zeropoint and gave no response whatever. Many gages sank with the five mortally-wounded ships they were mounted on; few of these gages were recovered. Some of the gages were shielded by ships' superstructures and gave abnormally low readings; in some instances the inter-

* *Arrangements had been made to send out a master timing signal, which was to start a number of recording instruments an instant before the explosion occurred. Actually, the signal was sent out a number of seconds too late. This delay was caused partly by imperfect reception of a preliminary radio signal and partly by human error. Plans were such that nothing short of this coincidence of ill luck could have thrown off the master signal. The great majority of instruments were not dependent on this signal, and the multiplicity of instruments was such that all principal types of information sought were achieved despite inoperativeness of individual groups of instruments.*

ference produced abnormally high readings.* Oddly enough, one of the most valuable of all the pressure results was that obtained from a specially-mounted beer can, whose graceless collapse filled an otherwise serious gap in the pressure story.

IMPULSE

The measurement of impulse, although less satisfactory than the measurement of pressure, was entirely adequate. Despite the timing signal failure mentioned previously, a number of good records of pressure-versus-time were obtained. From these, by the usual method of integrating, physicists computed the impulse values. As expected, the net impulse was practically nil except extremely close to the Zeropoint. At greater ranges the impulse delivered by the positive pressure phase was almost exactly counterbalanced by the negative phase, which started one-half to one second later.

But even though the *net impulse* was practically nil at most of the target vessels, the *net effect* was far from nil. It was, of course, the *impulse during the positive phase* which was responsible for the majority of

**Although the bomb detonated at approximately the planned altitude, its plan-view position was 1500 to 2000 ft. to the west of the intended bull's-eye ship NEVADA. How this discrepancy occurred has been the subject of long study; but no answer has been found. Incontrovertible evidence is available to disprove each of the dozen different hypotheses which may be advanced as explanation. No discrepancy of anything like this magnitude occurred in the long series of practice drops made.*

the havoc wrought. Many masts, for example, were bent by this positive phase; and they certainly were not straightened out again by the ensuing negative (suction) phase. Impulse values — and ship damage — were particularly great because both the *pressure* and the *duration of the positive phase* are exceptionally great in atomic bomb explosions. Destruction was far greater than would have resulted from high pressure alone, or long duration alone. The bomb reaped double havoc.

CONDENSATION CLOUD

The shock wave was not visible to the naked eye; but the progress of the ensuing suction was apparent enough. Racing closely on the heels of the fast-spreading shock wave, the suction wave had the form of a thin shell of rarefied air. Because this air was rarefied and thus cooled, the water molecules present condensed in myriad tiny droplets, millions of them in each cubic inch.

The result was the formation of a large zone of fog, called the condensation cloud. Some persons referred to it as the "Wilson Cloud," in honor of C. T. R. Wilson, who fifty years ago pioneered the study of fog and rain, and made thousands of experiments in which fogs were produced by sudden expansion of saturated vapor.

From a distance, the condensation cloud at first resembled a white hemisphere, dazzlingly bright, resting on the surface of the water. The hemisphere grew rapidly, of course, in accordance with the velocity of the suction wave. Thus its diameter increased initially at the rate of several thousand miles per hour; later, the increase proceeded at the more modest rate of about 780 miles per hour, the velocity of sound.

But this great hemisphere lasted only a few seconds. Its interior was rapidly burnt out by the trillion-watt fireball located at the center. Upward growth of the cloud was limited principally by too-low humidity in the upper strata of air; lateral growth was limited by the gradual dying off of the suction wave. The myriad droplets were evaporating fast. Within five seconds the cloud had become a great horizontal ring two miles in diameter, resting on the water and enclosing the fireball. In another five seconds the ring had disintegrated; only patches of cloud remained.

THE FIREBALL AND OPTICAL RADIATION

The fireball, unlike the condensation cloud, was no mere spectacle. It dealt serious injury to ships and test animals. Beginning its existence in the very process of distintegration of the bomb, it was of indescribable brightness during the first two seconds. Then, for about three seconds, it was obscured by the condensation cloud. At about five to eight seconds after Mike Hour it came back into view again. It grew, swept rapidly upward, and by ten to twenty seconds after Mike Hour the fireball had lost itself in the rapidly rising mushroom cloud.

The fireball's real punch occurred within the first half second. In this brief interval an appreciable fraction of the total energy released by the bomb sped outward at the velocity of 186,000 miles per second. It was in this interval that flash burns were produced on target equipment and animals.

The initial output of optical radiation was hundreds of trillions of watts, greater than the aggregate power output of all the electric light bulbs ever manufactured by man.

In the first few tenths of a second the fireball grew very rapidly. As it grew, each square inch of its surface became less brilliant, but there were, of course, more square inches in its surface. Accordingly, the total output of light decreased according to a somewhat complicated formula. Aerial photographs, analyzed with the help of densitometers, were particularly valuable in following the detailed course of this split-second life-history.

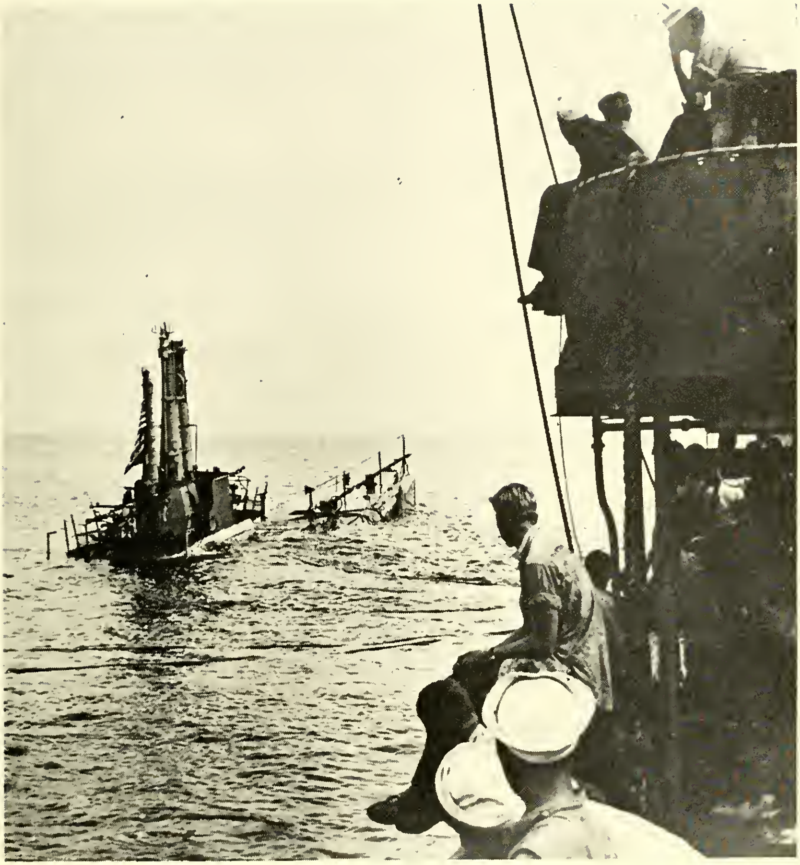
Photometrists found that the greatest surface temperature of the fireball was well above 100,000 degrees Fahrenheit. Interior temperatures were far higher. To observers 10 miles away, the illumination produced per square inch of fireball area was several times that of the sun at noon. The fireball produced a bluer light than the sun, which again indicates the fireball's greater intensity.

Although the fireball itself was rich in ultraviolet light, including light of the "vacuum ultraviolet" region, much of this light was cut off from observers by the intervening atmosphere. Practically no light of wavelengths less than 3000 Angstrom units was detected near sea level at ranges of twenty miles. Much infrared light was detected, although here again absorption by the atmosphere was severe. The water vapor content of the atmosphere was of course great, and such vapor is well known for its reluctance to transmit infrared light.

THE MUSHROOM

The mushroom, now the common symbol of the atomic age, was far more spectacular than any still photograph can suggest. Its height and statuesque beauty were impressive; but even more impressive was the speed of its writhing upward surge.

The speed of its ascent is understandable enough. When the bomb exploded, white hot gases instantly spread and filled a region about one-third of a mile in diameter. But these gases were very thin; their aggregate weight was extremely slight — about the same, in fact, as the weight of a hydrogen-filled balloon of equal diameter. Now a hydrogen-filled balloon of this fantastic size would have enough lift to raise *thousands of tons.* Such, then, was the magnitude of the buoyant force urging the fireball upward.



Crew of the submarine rescue vessel WIDGEON watch the test submerging of the submarine APOGON. The submerging operation was difficult; never before had there been occasion to submerge a submarine without crew aboard. The method used was to fill part of the ballast tanks with water, then suspend heavy weights from the bow and stern by cables of carefully chosen length. These weights overcame the submarine's residual buoyancy and drew her down to the desired depth. She could be surfaced again by pumping air back into her ballast tanks.

Plate 17

UPPER. Test A, the explosion in air; 9:00 a.m. on July 1, 1946. The hemispherical condensation cloud, lit by the white-hot fireball at the center, outshines the tropical sun. LOWER. The fireball starts its swift ascent into the stratosphere.

Plate 18

Test A's havoc-producing shock wave sweeps over the target ships and races towards deserted Bikini beach while the mushroom writhes silently upward.

Plate 19

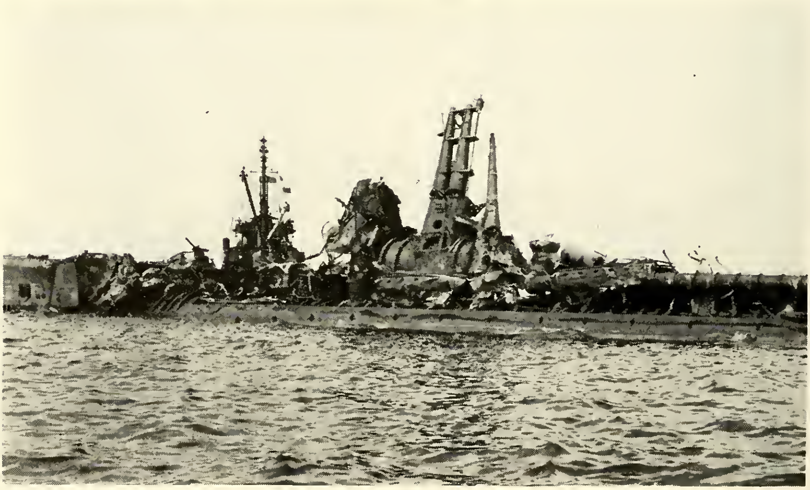
The mushroom growing out of the Test A explosion in air has now reached an altitude of five miles. Veiling the mushroom top is the ice cap, or scarf cloud, believed to be composed of myriad tiny ice crystals. The mushroom itself is a mixture of vapor, smoke, soot, and radioactive fission products.

Plate 20

The light carrier INDEPENDENCE, located between 1000 feet and ½ mile from the projected Zeropoint, shows severe damage. Her 600 foot flight deck is broken in several places. Part of the deck planking has burned. Her four stacks have been demolished, and her antenna masts are bent or broken.

INDEPENDENCE'S port quarter, being nearest to the Zeropoint, took the worst beating; much of the wreckage here was unrecognizable. A fire broke out on the hangar deck, adding to the damage already done by the shock wave. Huge beams of heavy gage steel had been ripped loose. The plating above the waterline was damaged over a considerable area.

A monitor from the Radioactivity Group uses a Geiger counter to measure the radioactivity on the SKATE. This submarine, of modern heavy construction, was located within ½ mile of the Test A Zeropoint. Being fully surfaced, she took terrific punishment. Most of her superstructure was stripped off, exposing a large area of her pressure hull.



General view of damage produced on the submarine SKATE in Test A. Her conning tower fairwater was badly smashed, and her bridge also. Periscope and radar shears were bent. Inside her pressure hull, however, damage was not severe; within three days she made a successful surface run under her own power.

Plate 22

Battered almost beyond recognition is this Navy seaplane which had been placed on the stern of the battleship NEVADA, located 1500 to 2000 feet from the Test A actual Zeropoint. Besides producing mechanical damage, the explosion caused fires in combustible materials at distances as great as one or two miles. Various other materials were melted or scorched. Army quartermaster stores proved to be especially vulnerable.

The NEVADA, bull's-eye battleship, escaped with moderate damage. The bomb, instead of detonating directly above her, detonated 1500 to 2000 feet away. NEVADA'S two topmasts failed, and the starboard yardarm also. Her weather deck was dished moderately. Some stanchions and bulkheads were distorted. However, her hull was practically undamaged, and her interior was little disturbed. The deck-loaded gear suffered severely.

Plate 23

UPPER. Insidious almost beyond belief, the great mushroom cloud conjured in Test A harbored radioactive fission products equivalent to hundreds of tons of radium. Manned planes were kept miles away, but drone planes were guided directly through the cloud, sampling its content with the aid of filters mounted in boxes attached to the undersides of the planes' wings. Removing the filters was done with great care. LOWER. A radioactivity check is made on a goat exposed to the Test A explosion.

Plate 24

The fireball rose initially at a rate of more than one hundred miles per hour. Within twenty seconds it transformed itself into the fireless head of the mushroom, now one mile high. Two minutes later the mushroom's altitude was five miles; five minutes later it was seven miles, one mile higher than Mt. Everest.

As the mushroom head rose at express-train speed, it sucked air in beneath it. Scooped up in this turbulent trailing festoon, called the stem, were soot from the stacks of the nearer target vessels, smoke from the flash-burned decks and equipment, and water vapor.*

The mushroom head broadened as it rose; eventually it attained a width of nearly two miles. The air rising in the mushroom head became cooler as it rose and expanded; air pushed upward just above the mushroom head was cooled also. This cooling resulted, of course, in condensation. A remarkable phenomenon occurred: a thin white cap or scarf cloud appeared lying just above the mushroom top and cleanly separated from it. It is probable, although not certain, that this consisted not of water droplets but of very

* *The mushroom contained also various unusual gases created by the bomb's ionizing radiations. These radiations were partially absorbed by the nitrogen and oxygen molecules of the air and the result was: nitrogen molecules were broken up into individual nitrogen atoms; and the oxygen molecules were broken into individual oxygen atoms. When the unmated nitrogen and oxygen atoms collided, they immediately joined to form molecules containing oxygen and nitrogen together. Such molecules have an apricot color, and traces of this color were clearly visible in the A-Day mushroom.*

small ice crystals. Such an ice-cap, never before produced by man, can only form when the meteorological conditions are exactly right.

The mushroom did no damage, but it was far more fearsome than its soft white form could suggest. In it were shrouded the bomb's deadly fission products; for in such a "self-cleansing" explosion as this, nearly all the bomb products remain in the air and are carried aloft in the mushroom. The amount of radioactive fission products infesting the cloud was small in terms of weight. But its potency was impressive, being temporarily equivalent to hundreds of tons of radium. (The world's total supply of concentrated radium amounts to only a few pounds.) If an aviator had flown through the mushroom and inhaled its air, he would probably have died as a result. If an aviator's plane had failed and he had been forced to jump, his parachute would have been of little avail if it carried him into this cloud.

The mushroom's menace was a lingering one. Its fission products settled out very slowly, endangering everything lying in its path. The menace became the more insidious when, about one hour after the explosion, the cloud lost its characteristic shape and became visually indistinguishable from other clouds in the area.

Airmen continued to track it for many hours in B-29 planes carrying Geiger counters; they found that the affected air region followed the course predicted by the aerologists, and that only deserted ocean areas received the continuous and invisible fall-out of radioactive materials.

Fortunately, the contaminated region healed itself relatively promptly. The fission products themselves lost a large fraction of their potency in a matter of hours, and lateral and vertical mixing with unaffected air proceeded rapidly. Within a short period the materials were dispersed throughout thousands of cubic miles of air. The materials were now so extremely dilute as to be harmless. Nevertheless, various scientific groups in America and in Europe are reported in the newspapers as having detected slight changes in the radioactivity in the atmosphere some days after the explosion. There is no doubt that, like the ashes thrown into the air in the explosion of the Krakatao many years ago, the fission products circled the globe for many months.

NUCLEAR RADIATION

Gamma radiation dominated the repertory of nuclear radiations. Alpha particles, beta particles, and neutrons were, of course, produced in abundance, but being light particles they were rather effectively blocked or slowed by collision with atoms in the air. Many of them failed to penetrate more than ten or a hundred feet of air; few of them reached beyond the innermost target vessels. And even on these vessels their effects were of questionable importance in view of the great damage caused by the shock wave, heat flash, and gamma radiation.

The gamma radiation's maximum power was displayed in the periods of a few seconds. Geiger counters on target vessels demonstrated that an enormous burst of gamma radiation was produced during the instant when the bomb was detonating; additional gamma radiation came from the fission products in the fireball. But after the mushroom had borne its poisonous pall to high altitude the gamma radiation at sea level was very weak indeed.

The total amount of gamma radiation reaching the target vessels was large. In many instances the photographic film gages showed aggregate dosages of the order of hundreds or thousands of roentgens.* The total output of gamma radiation was so great that if by some feat of magic it could have been distributed uniformly among several million persons it would have eventually killed or seriously injured all of them. Of course, in any practical situation the number of persons affected would be very much smaller.

The gamma radiation was of many wavelengths, covering an appreciable spectral band. The typical

* *The roentgen is a unit of cumulative intensity of ionizing nuclear radiation. Radiation which is sufficiently intense and prolonged to produce a billion ion pairs in a single cubic centimeter of air represents approximately one roentgen. One tenth of a roentgen was adopted by Joint Task Force One as the maximum safe dosage per day. Fifty or 100 roentgens per day can be seriously harmful to man, and a few hundreds roentgens may prove fatal.*

wavelength was roughly one ten-billionth of a centimeter; 25,000,000,000 such waves would be required to cover one inch. The *energies* of the individual gamma ray photons, being in exact inverse proportion to the wavelength, were tremendous. A typical photon had an energy of about one million electron volts. The high energy of these photons meant that they had great penetrating power — greater than that of typical X-rays. In practical terms this meant that no ordinary screen of steel, lead, or other material known to man could successfully block off the radiation. Very heavy steel walls, several inches thick, would reduce the intensity by an appreciable factor and foot-thick steel walls would reduce the intensity to a fraction of the original value. But in the face of such extremely intense radiation as that which struck the target ships, even a fraction of the initial intensity might do serious and lasting harm.

To compute the total potential effectiveness of nuclear radiations on ships' crews has not proved to be easy. To be fully meaningful, such computations must take into account many factors. The most obvious of these factors is the distance of the ship from the Zero-point. All radiations are, of course, less intense at greater distances and are therefore less effective there. But the situation is complicated; the decrease in intensity of some kinds of radiation is much more pronounced than for others. Even fast and slow neutrons show unlike deference to distance. Gamma rays too are not of uniform behavior. For each distance of interest, it is necessary to compute separately each radiation's effectiveness, and then to combine the results to obtain a measure of the total effectiveness. Another important factor is the altitude of the Zeropoint. Obviously, if the bomb detonates almost at the surface of the ocean, the radiation will probably enter the ship through the side, and persons well below the waterline may be almost perfectly protected by the intervening water. But if the bomb detonates directly overhead, the thickness of the decks will be of principal importance. The type of ship, too, makes a difference. Thick-walled battleships must be expected to give far greater protection than thin-walled destroyers. The distribution of the men throughout the ship must be considered too. Persons far below decks may escape relatively lightly even when persons exposed topside receive fatal doses. In a later section the attempt is made to state the over-all effect of nuclear radiation on ships' personnel.

No one knows what psychic catastrophe the gamma radiation might wreak on the doomed crews. The radiation can claim these remorseless attributes: it is invisible, so that no one can see it coming; ordinary walls do not stop it, so that "no hiding place down here" applies all too fully; medical science knows of no way to save severely exposed persons; and the radiation produces no immediately apparent effect, so that overly apprehensive persons entirely out of range may be convinced death is at hand. This last factor is probably more important than it logically should be since persons almost always overestimate the closeness of explosions. Explosions a considerable distance away may sound next door.

DAMAGE TO SHIPS

The fact that five ships were sunk by the A-Day explosion is of little absolute importance. The number might have been considerably greater or less, depending on exactly where the bomb exploded and on the exact disposition of the ships.

Damage to ships should be evaluated in the light of their locations. Rough indication of the locations with respect to the bulls-eye ship NEVADA is provided by Figure 4. Approximately twenty of the target ships were located within the central area of one square mile. Many of the other ships were spaced along radiating lines or spokes. These lines were curved slightly, so that the inner ships could not shield their outer neighbors.

The majority of the ships carried considerable loads of fuel and ammunition. Thus secondary effects, such as fires and ammunition explosions, were evaluated as well as the primary effects. Ships in the upwind sector, however, carried only very small loads of fuel. These loads were kept small so that, in the event that the fuel caught fire and spilled out onto the Lagoon

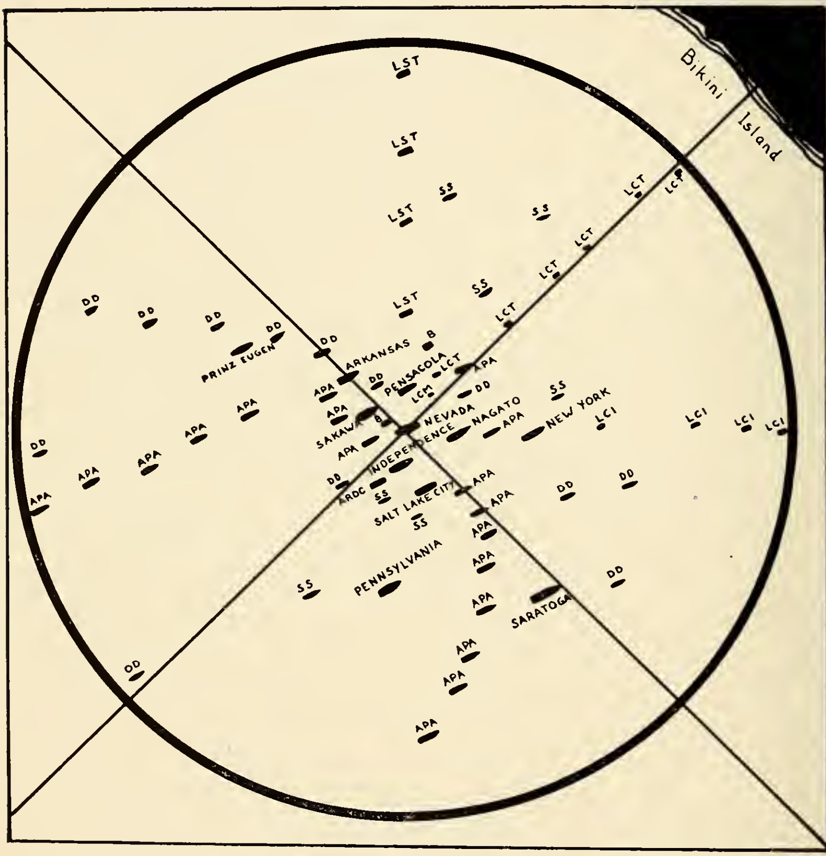


Fig. 4. Test A Target Array.

surface, it could not envelop scores of other ships, consuming them and their important cargoes of test animals and instruments. Such danger was heightened, of course, by the abnormally close spacing of the ships.

What struck the ships first? Undoubtedly it was the thermal radiation and the gamma radiation. These struck the ships within the first thousandth of a second. The thermal radiation lasted only a few seconds, ceasing with the extinction of the fireball. The gamma radiation was greatly reduced in intensity as soon as the mushroom got underway in its climb to the stratosphere. The thermal radiation produced serious effects on exposed test animals and on various kinds of ship equipment, but it produced very little serious damage to ships' hulls and superstructures. Gamma radiation likewise had relatively little effect on ship structures.

The shock wave did the damage. The impulse it delivered, with its extraordinarily high peak pressures and its long-lasting positive pressure phase, was irresistible on the nearest ships. It bent masts, depressed decks, crumpled stacks, unseated cranes, dished side plating. It twisted and broke the flight deck of the nearer aircraft carrier and ripped nearly all the superstructure off a surfaced submarine nearby.

Detailed surveys of damage had to wait until the mammoth re-entry maneuver had been accomplished.

Drone planes were first to make close approach to the target center. Only eight minutes after Mike Hour a B-17 drone entered the mushroom at 24,000 feet. A few minutes later three other B-17's swung across at altitudes of 30,000, 18,000 and 13,000 feet. Three F6F drones made transits at 20,000, 15,000 and 10,000 feet. The planes collected air samples and returned to base; their samples were sent to Kwajalein for radiological analysis.

Four TBM planes were launched from SAIDOR a few minutes after Mike Hour. They obtained valuable photographs of sinking ships, but their main job was to assist the controlling of drone boats soon to be launched. No manned planes flew directly over the Zeropoint until four hours after Mike Hour.

The LVCP drone boats started towards the target array forty-four minutes after Mike Hour. Their progress was controlled by radio signals sent from BEGOR, which lay just outside the long Bikini-Enyu reef. The leading LCVP reached the target center in one hour, and picked up water samples. Two hours later these samples had been put aboard the destroyer MOALE, which was soon speeding to Kwajalein where the samples were to be analyzed.

Manned boats first re-entered the Lagoon two hours after Mike Hour. First to enter were the six PGM's of the radiological safety party. A little later, twenty LCPL's entered also. These boats cautiously threaded their way throughout the target area, using their Geiger counters to detect any unsafe areas. Few such "hot" or "Geiger sour" areas were found by this patrol party.

The salvage vessels now entered the lagoon and went to work to put out fires on several of the target ships.

At 2:30 p.m. the Task Force Commander announced over his radio circuits that the lagoon was safe for entrance by all vessels. Ships of the Technical Group entered almost at once. The flagship MT. McKINLEY entered a few minutes later, and the other ships followed.

By sundown, eighteen of the target ships had been reboarded by special boarding teams, although regular ships' teams were not put aboard until later. Many animals were recovered and transferred to BURLESON; a number of scientific instruments were recovered also.

In the following few days the remaining animals and instruments were recovered. While these were being studied, diving and salvage operations were rushed. An unsuccessful attempt was made to beach the Japanese cruiser SAKAWA, which was afire for 24 hours. Soon after she was taken in tow, she keeled over to port and sank by the stern. The aircraft carrier INDEPENDENCE and the concrete oil barge YO-160, both badly damaged, were moved to more appropriate berths. The submarine SKATE was beached in shallow water off Enyu Island.

Inspection teams now swarmed over the ships, examining every damaged item. The special data forms, printed long in advance, proved their worth. They insured orderly and thorough inspection, and the recording of results in a consistently uniform manner.*

Six days after A-Day the staff of the Director of Ship Material completed an 85-page provisional report on damage to ships and animals. Within thirty days this group had completed an interim report of 2000 pages. Five months later it had finished a monumental report of 150 *volumes*. The full story is now available as to the damage wrought in the five seconds after the detonation on A-Day.

The GILLIAM, closest of all the target ships, and *only* ship located within 1000 ft. of the projected Zero-point sank within one minute. She was a merchant-type attack transport and was 446 feet long. Divers later found that her superstructure was smashed almost beyond recognition, and her hull also was utterly wrecked. She proved beyond the slightest doubt that a ship of this type could not hope to stand up against the atomic bomb at close range.

The ANDERSON, a 338-foot destroyer located between 1000 ft. and one-half mile, sank within eight minutes. Pictures taken from a PBM photographic

* *The difficulty of this job is hard to appreciate. On a single ship such as the INDEPENDENCE, for example, there were literally* thousands *of compartments, rooms, and installations to inspect. Hundreds of the rooms showed severe damage, and hundreds more showed light damage. On the flight and hangar decks, too, there were enormous areas of wreckage. Merely classifying an area as "wrecked" or "partially wrecked" would have been relatively easy; but to describe the wreckage in detail, and in terms suitable for later practical use by engineers, ordnance experts, communications men, medical men, fire control personnel, and naval architects, was truly a Herculean task.*

plane show her visible through the smoke cloud one minute after Mike Hour. Much of the upper part of her superstructure was missing entirely. A fire was burning amidships. A minute later the fire appeared to be growing in intensity and to be spreading aft along the port side. Still later, the fire amidships increased markedly, and the entire central section of the ship was in flames. She began to list; within four minutes of Mike Hour she was on her beam ends. A cloud intervened for a few seconds, after which she was found to have rolled still further on her port side. Her fires now appeared extinguished, but she was settling fast. By six minutes after Mike Hour only a small portion of her bottom was visible, and in another two minutes she was gone.

Divers later found her resting on her side in about 200 feet of water. They made an extensive survey of her smashed superstructure and confirmed that much of it was missing or unrecognizable. Her deck was in very bad condition, and her shell plating also.

The CARLISLE, an attack transport much like the GILLIAM, sank within forty minutes. She too was within one-half mile of the projected Zeropoint. Divers found her lying nearly upright, with about five degrees list to port. Her condition was generally similar to that of the ANDERSON.

The LAMSON, a 344-foot destroyer, located within one-half mile of the projected Zeropoint, sank within eight hours. Early photographs showed her listing to starboard with bridge structure badly smashed. Guns were visible, but the mast and other light structures were missing. Observers airborne in PBM Charlie found the ship lying over on her starboard side about forty-five minutes after Mike Hour; her bridge structure was underwater and the port side of her bottom was above the surface. Later she floated bottom up for a short while, and then sank. Divers reported her condition as being much like that of the ANDERSON.

The Japanese light cruiser SAKAWA, located within one-half mile of the projected Zeropoint, sank in mid-morning on the day after the explosion. A severe fire burned in her stern for nearly twenty-four hours. She showed severe structural damage topside. Her hull too suffered major damage; her stern was breached in several places. Water entered steadily, and her draft increased seriously. Despite difficult radiological conditions prevailing, the attempt was made to tow her to a nearby beach. But by this time her stern was awash and her stability had been reduced to the vanishing point. Soon after being taken in tow she keeled over to port at an angle of 85 degrees and sank by the stern.

Sinkings made headlines, but it was the surviving ships which provided the largest amount of precise information. The light carrier INDEPENDENCE, located between 1000 ft. and one-half mile from the projected Zeropoint, showed perhaps the most striking damage. Her 600-foot long flight deck was broken in several places and badly buckled. The port corner of the flight deck was blown off. Part of the deck planking was burned away. All four stacks were demolished, the flight deck crane was knocked over, and both airplane elevator platforms were blown overboard. Antenna masts were bent or broken. A fire broke out on the hangar deck, adding to the wreckage already produced by the shock wave. Huge vertical beams of heavy gage steel had been ripped loose; in some instances they were left hanging in grotesque array. Her plating above the waterline was damaged over a considerable area, and holes were blown in the sides enclosing the hangar deck. Huge wrinkles disfigured her starboard side. Her interior showed extensive damage also. Her port quarter, being nearest to the Zeropoint, took the worst beating; much of the wreckage here was unrecognizable.

The submarine SKATE, over 300 feet long and of modern heavy construction, was located within one-half mile of the projected Zeropoint. She was on the surface, and as a result lost nearly all her superstructure. The conning tower fairwater and the bridge were badly damaged; the same was true of the weather deck along most of her length. The periscope and radar shears were bent to starboard. Aft of the conning tower most of the decking, the majority of the free-flooding superstructure, and many pipes and fittings were bent, smashed, or even blown over the side. The bridge structure was folded together upon itself in front of the conning tower. Nearly half of the superstructure forward was wrecked. The side lights were shattered and the stern light was missing. The after windlass was inoperable. Inside the pressure hull, however, damage was not severe; within three days she made a successful surface run under her own power. Submerging would have been unsafe, and was not attempted.

The ARKANSAS, oldest battleship of the United States Fleet, was one of the three major combatant ships within one-half mile of the Zeropoint. She suffered heavy damage. When the lagoon was first reentered, she was still sending up clouds of smoke from smouldering fires on her decks. But the shock wave did the most damage. Stacks, masts, and mast supporting structures suffered, as well as pipe rails, bulwarks, stowage spaces. Much dishing occurred. Many doors, stanchions, and bulkheads were badly damaged. ARKANSAS was definitely put out of action and would have required extensive repairs at a principal naval base.

The NEVADA, bull's-eye battleship, escaped with moderate damage. The bomb, instead of detonating directly above her, detonated 1500 to 2000 feet away. Both topmasts failed, and the starboard yardarm also. The weather deck was dished moderately. Some stanchions and bulkheads were distorted. Painted surfaces on exposed parts of the superstructure were blackened. However, her hull was practically undamaged, and her interior was little disturbed.

The CRITTENDEN, another 426-foot merchant-type attack transport, received heavy damage of the same general type described in the previous paragraph.

Other ships badly mauled were: the cruisers SALT LAKE CITY and PENSACOLA, and the destroyers HUGHES and RHIND. The concrete oil barge YO-160 suffered lesser damage, and significant damage was suffered by the aircraft carrier SARATOGA, the destroyer TALBOT, the concrete drydock ARDC-13, the merchant-type attack transport DAWSON, and LST-52. Among the other ships suffering negligible to moderate damage were the battleships NEW YORK and PENNSYLVANIA.

WHAT IS DAMAGE?

How was the wealth of ship-damage data to be summarized? This question puzzled Admiral Parsons' technical experts from the outset. Various schemes were proposed for synthesizing the almost endless stream of data into simple generalizations. It would be convenient to be able to say: "Ships are sunk at ranges as great as X yards, badly damaged out to Y yards, and slightly damaged out to Z yards." But it was recognized from the outset that no such simple rules could be expected. Each type of ship has a different vulnerability; and even within a single type of ship, newer ships may not be of the same vulnerability as older ships. Ship aspect, too, must be important. A ship caught broadside might be capsized where a bow-on ship might remain upright.

Almost endless complications arise when a definition of damage is sought. In the midst of a battle, the important damage is that which prevents the ship from fighting with full effectiveness. Here damage means *loss of fighting efficiency.* Mere loss of a rudder or failure of the radar sets may be regarded by combat crews as disastrous damage.

When the crippled ship limps into port, damage means something quite different. It is expressed in *weeks to get the ship back into action.* Thus shipyard engineers classify any damage as light if repairs can be completed in a few days.

Foremen rate damage in terms of *man-hours* to repair the ship; accountants express damage in terms of dollars.

From the scientific point of view, damage is a measure of how many parts are injured, and how elaborate the injuries are. Of no concern here is the matter of importance of the parts, or the time needed to repair them. Some persons may be interested principally in damage to ship's machinery or electronic equipment; other persons may regard damage to guns and hull as especially vital.

A nice question is whether radioactivity on the target ships represents damage to the ships or injury to the crews. The ships are contaminated, but it is the crews which suffer.

Now the *loss of fighting efficiency* concept of damage is certainly of very great importance. But it is hard to define exactly. Failure of main turrets might constitute serious loss of fighting efficiency in action against surface ships, but it would have no bearing on fighting enemy planes. Loss of radar is almost fatal in a battle fought on a cloudy night, but it is far less serious in a battle fought in brilliant sunshine. Loss of speed may be only of minor importance on some operations, and fatal in others. Another difficulty is duration of loss of fighting efficiency. How can we compare permanent loss of speed or fire-power with loss which can be repaired in an hour or two by the ship's crew? We can answer this only if we know how long the battle is to last.

The solution adopted was to use several of these damage concepts in parallel. Rough definitions were drawn up, and the individual data were sorted out accordingly. Totals were compiled, and the conclusions came into view.

Some major conclusions are these:

1. The majority of lighter warships located within a critical radius somewhat less than one-half mile away may be expected to be sunk by an atomic bombing attack such as that executed on A-Day.
2. Heavy warships located within one-half mile may survive, but their superstructures will be badly damaged and the ships will be put out of action; extensive repairs

at a principal naval base will be required.

3. Ships more than three-fourths of a mile away may suffer damage, but the damage will be relatively light in typical cases.
4. Among the most badly damaged ships, damage to superstructures was very severe; hulls escaped relatively lightly. Damage extends to nearly all kinds of mechanical and electrical equipment.

DAMAGE TO SPECIAL TEST EQUIPMENT

Ships' decks, the only platforms in the neighborhood of the Zeropoint, had been generously covered with special test equipment of nearly every imaginable kind. Colonel J. D. Frederick's DSM Army Ground Group had exposed equipment lent by all principal branches of the Army, including the Air Forces, Engineer Corps, Signal Corps, Ordnance Department, Chemical Corps, and Quartermaster Corps. Much Navy equipment was exposed also, principally by the DSM Ordnance Group under Captain E. B. Mott, the DSM Aeronautics Group under Captain T. C. Lonnquest, the DSM Electronics Group under Captain C. L. Engelman, and the relatively small DSM Supplies and Accounts Group. So extensive was the equipment that seven volumes of several hundred pages each were required to summarize the results obtained.

Some of the heavier items exposed were tanks, weapon carriers, trucks, amphibious ducks (or DUKW's), tractors, airplanes. Lighter items included guns, mortars, rocket launchers, rifles, torpedoes, mines, depth charges, bombs, fuzes, grenades, rockets, flares, telescopes, periscopes, infrared snooperscopes, altimeters, fire extinguishers, water distillation equipment, odographs, knives, watches, telephones, switches, gas masks, flasks, samples of oil, grease, gasoline. Lists of clothing and supplies samples are almost endless; they included canned apples, apricots, tomato juice, string beans, creamed corn, bacon, turkey, butter. For exposure inside ships' refrigerators, pork loins, hams, sausage, beef, and frozen fish were taken along. There were jackets, trousers, parkas, undershirts, drawers, socks, boots, helmets, DDT, soap, and even skis.

Valuable results, impossible to summarize adequately, were obtained. Combustible materials had a tendency to catch fire, presumably due to the thermal radiation. This occurred even at distances of one or two miles from the Zeropoint. Of course, many of these fires could have been brought under control quickly by ships' crews, if there had been crews aboard.

As expected, thermal radiation showed a great preference for black surfaces. In many instances black-painted objects, and even black writing, was burned although nearby white surfaces were almost untouched. Some objects melted. Rubber objects located near the Zeropoint were scorched or burnt.

Light metal surfaces, such as exteriors of trucks and aircraft structures, were frequently demolished.

Bombs and torpedoes exploded in a number of instances, but probably not as a direct result of the atomic bomb explosion. Secondary causes, such as fires, were presumably responsible.

Army quartermaster stores and other miscellaneous equipment exposed showed greater vulnerability, ordinarily, than normal naval deck gear.

INJURY TO ANIMALS

The test animals which had been placed on the twenty-two target vessels by Captain Draeger's DSM Naval Medical Research Section were removed as soon as possible after the detonation. Some of the animals were removed on the afternoon of A-Day; others were removed on the two following days. They were brought to the BURLESON, where injured animals were given good medical care and all animals were examined thoroughly.*

In all, about 35 percent of the animals used in Test A had been killed as of late September, 1946. Ten percent died from air blast, 15 percent from radioactivity, and 10 percent were killed for study.

* *Goats are imperturbable animals. A goat aboard the NIAGARA was photographed by a close-up automatic motion picture camera just as the shock wave struck. The pictures give a clear view of the goat, and show him munching his hay without interruption as the shock wave struck and debris flew all about.*

Air blast, as expected, was particularly injurious to the exposed animals. Principal symptoms of air blast injury were contusions and lung hemorrhages.

Damage to animal's eyes was negligible.*

Flash burns produced by the thermal radiation did considerable damage to animals situated in a direct line-of-sight from the detonation. Fur, of course, provided important protection. The protection afforded by anti-flash creams and clothing was evaluated successfully; knowledge is now adequate for giving personnel maximum feasible protection against burns.

Gamma radiation results developed more slowly. Animals receiving only slight doses often appeared entirely normal at first. Later some developed hemorrhagic patches; a few showed partial loss of hair and very few developed testicular atrophy. The more heavily-exposed animals exhibited hyper-irritability, muscular weakness, diarrhea, and increased rate of respiration. Some of these were moribund, with exaggeration of symptoms, bloody diarrhea, and inability to stand. These symptoms appeared to have caused the animals no intense pain.

Just how does gamma radiation deal its blow? This was one of the questions uppermost in the minds of Captain R. H. Draeger and Captain Shields Warren as they studied the animals taken off the target ships.

* *This is in accord with experience at Hiroshima and Nagasaki, where blindness was caused by dust and smoke, rather than by the brilliance of the light.*

Their answer was soon forthcoming. By combining what had been learned in Japan with the added information garnered at Bikini, a fairly complete understanding was arrived at.

The answer was a triple one: gamma radiation reduces the supply of new white blood corpuscles, it reduces the supply of new red corpuscles, and it reduces the supply of materials necessary to prevent excessive bleeding.

The most important effect is the reduction of the supply of white blood corpuscles. A very severe dose of gamma radiation completely destroys the bone marrow's ability to produce white blood corpuscles; no new white corpuscles are produced. This would perhaps not be serious if the existing white corpuscles could last indefinitely. But they do not: in the natural course of events most of them disappear in about two weeks. Their absence is serious since the body depends on them to destroy infections. With no white blood corpuscles, the body is easily overpowered by any of the common infections threatening from within or without.

Red blood corpuscles, too, are a product of bone marrow. They too face extinction when a large dose of gamma radiation affects the bone marrow. Existing red blood corpuscles may carry on for a month or more, but eventually there are few left; the anemia is serious.

The third important effect of severe exposure to gamma radiation is reduction in the body's ability to prevent excessive bleeding. The injured bone marrow is no longer able to produce the so-called platelets which normally circulate in the blood. Platelets are the particles that produce the enzymes essential to blood clotting. Without platelets, the supply of the enzyme vanishes. Then, when bleeding starts anywhere in the body, the blood is unable to form clots; bleeding continues. Hemorrhagic patches may appear almost anywhere on the body's exterior or interior; such patches may appear, for example, on the skin or on mucous membranes. Severe hemorrhages may cause death.*

Useful correlations of *injury* and *distance of the animals from the Zeropoint* were made. Additional correlations were made between *injury* and *intensity of effect responsible.* This latter correlation was made, of course, taking full account of the exact degrees of protection afforded the animals. Captain Draeger's records show the exact location of each animal; and by combining these data with the measured values of peak pressure, thermal radiations, and gamma radiation, very useful analyses result.

The effect of the gamma-ray dosage given the mice will not be known for some time. These animals were

* *Although exposure of the entire body to a few hundred roentgens may be fatal, exposure of only a small part of the body may produce relatively little injury. There is at least one laboratory case on record in which a patient's brain was given an X-ray exposure of 24,000 roentgens, and the patient survived.*

placed so as to receive non-lethal dosage, in order that genetic effects, if any, might be followed over several generations of progeny. Immediately after the test, the mice were flown back to the National Cancer Institute. They were bred, and even by late September of 1946 a few litters had been born. These litters were apparently normal; but it was still too soon to tell whether cancer would develop.*

The results obtained on animals and the extensive radiation and pressure data obtained form a firm basis for estimating the ranges at which exposed and protected crew members would be seriously injured; the symptoms of injury are far better understood, and advances in diagnosis and treatment have been made.

One general conclusion is that casualties caused by the shock wave may be expected to be high for persons in exposed positions within one half mile of the projected Zeropoint. Thermal radiation also may be expected to be very harmful to exposed personnel. Within the area of extensive blast damage to ship superstructures, nuclear radiation may well prove fatal; thin walls of steel cannot insure protection, and even thick walls are an imperfect answer.

* *Gamma radiation is probably capable of producing chromosome changes which can be transmitted to progeny. It is likely that the great majority of such chromosome changes are sufficiently unfavorable that no progeny would be born alive; early prenatal death would be more likely. Whether or not any mutations with power of survival will result from the animals exposed at Bikini cannot be decided for some time; such mutations would not be expected to show up for several generations.*

8. TEST B: UNDERWATER EXPLOSION

Test A was over. Sunken ships had been marked with buoys. Inspections were complete. A few repairs were made to damaged ships; some wrecked equipment was jettisoned.

Eight Congressmen and thirty-nine press and radio representatives returned to the United States. The press representatives had radioed 1,000,000 words on Test A to their home agencies. The press ship APPALACHIAN made an interim trip to Pearl Harbor; PANAMINT and BLUE RIDGE made trips to Truk, Guam, and other islands; SHANGRI-LA returned to Roi.

The weather was good, and the 42,000 men of the Task Force made excellent use of the recreation areas.*

** The most leavening event of the interval between the tests was a practical joke perpetrated by two members of the Bureau of Ordnance Instrumentation Group at the expense of their scientific colleagues. On the evening of A-Day, after the support ships had re-entered the Lagoon, Dr. C. W. Wyckoff and his friends on the KENNETH WHITING were leaning against the railing at the fantail, staring idly across the dark water. They had got up at 4:00 a.m., and they were pretty well exhausted; they were relieved that the Test had gone off successfully, and that there was said to be no dangerous radioactivity about. Suddenly Dr. Wyckoff's friends pointed to the water beneath them. The water there*

The target fleet was rearranged somewhat. The central ship was to be LSM-60; the bomb was to be suspended some distance beneath her in a watertight steel caisson. An especially tall antenna mast had been installed to permit line-of-sight transmission of the coded radio signal which was to fire the bomb.

Nearest to the LSM-60, but well over five hundred ft. away, were the aircraft carrier SARATOGA and the thirty-four year old battleship ARKANSAS. These were both moored broadside to the bomb, to receive the maximum impact. Nearby were the concrete oil barge YO-160, the submarines PILOTFISH, SKIPJACK, and APOGON, and the Japanese battleship NAGATO. In all there were seventy-four target vessels fixed in predetermined positions. Roughly forty ships and/or small craft were located within one mile of the Zero-point, and twenty of these were actually within one half mile.

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was distinctly luminous. They watched fascinated, then called more colleagues. They exchanged anxious questions as to whether a chance accumulation of radioactive materials might be the cause. If so, gamma radiation might that very moment be penetrating their bodies. They called Dr. J. E. Henderson, who arrived quickly bringing, on sudden inspiration, a piece of radioactive glass picked up months before at Alamogordo, New Mexico. Borrowing a Geiger counter, he quickly found that the mysterious glow was harmless and certainly a hoax, but he told no one. Instead, he surreptitiously placed the radioactive glass near the Geiger counter and allowed his colleagues to come to the dread conclusion that the glow was indeed highly radioactive. But before the alarm had reached too high a pitch, he made a confession, and Dr. Wyckoff reeled in the long black string by which his waterproof flashlight had been suspended.

Six of the eight submarines used were placed in submerged positions, since it appeared certain that the bomb would deliver its greatest punch underwater. Placing the submarines in submerged positions some distance above the bottom was not easy. The Navy had never before had occasion to attempt such a feat. Not only must the submarines be fixed at the right depth and in normal horizontal position, but the arrangement must be secure enough to last for weeks if necessary; and the submarines were to be raised again after the explosion. A method of submerging which was found satisfactory was to flood certain ballast tanks and then attach heavy weights to the submarine's bow and stern by means of long chains of carefully chosen length. The weights overcame the submarine's residual positive buoyancy and drew her down until the weights themselves rested on the bottom, leaving the submarine at the desired depth. The submarine could be surfaced later by pumping air back into the flooded ballast tanks. The entire operation was controlled from a salvage ship. The illustration Plate XVII shows the submarine APOGON in the process of submerging.

For the underwater explosion, elaborate preparations were made for measuring wave heights. Waves of unprecedented height were expected, and a unique opportunity was presented for studying generation and propagation of giant waves.

Preparing the highly-specialized instruments was the responsibility of Mr. N. J. Holter, head of the

Wave Motion Section of the Oceanographic Group.* Much reliance was placed on photography. Tower cameras on Bikini, Amen, and Enyu Islands were synchronized in a wave photography network controlled by radio. Cameras on three photographic planes were brought into the same network. Each camera was to take a photograph every three seconds.

Television was used also. Two transmitters, operating in the 200 megacycle band, were placed in the Bikini towers; ten receivers were used, several of them being mounted in PBM planes.

Many direct-reading wave-height gages were readied. Thirty of these, called turtles, were laid directly on the lagoon bottom. When a wave crest passed, the hydrostatic pressure on the bottom increased. Water was forced into the instrument through a fine capillary tube, a Bourdon-type pressure element was actuated, and a small pen drew a significant line on a slowly-revolving chart. Use of the capillary tube frequency filter was essential; it prevented the apparatus from being wrecked by the extremely intense underwater shock wave, which reached the apparatus a few moments before the water waves themselves swept past. The underwater shock wave came and went within a

* *Lieutenant Commander F. G. Morris was officer in charge of the Wave Measurement Section. Group leaders were Dr. W. K. Lyon, Lieutenant C. Sklaw (Navy), Mr. H. W. Iverson, Prof. Alexander Forbes, and Mr. A. C. Vine. Very important parts in this work were played by Dean M. P. O'Brien, Mr. J. D. Isaacs, and Lieutenant J. H. Chamblin.*

few thousandths of a second, and failed to penetrate the capillary tube appreciably; but the slow-moving water wave had no trouble in exerting its effect through this tube.* A number of bottom-mounted hydrophones (inductiphones) were used also. These, too, measured wave height in terms of excess pressure at the bottom of the lagoon.

Some wave-height gages were mounted directly on the target vessels. These gages, called portable recording echo sounders, made continual records of distances to the lagoon bottom. Thus as a ship rose and fell on a great wave, its changing elevation was recorded.† Some echo sounders were mounted on buoys, which rose and fell more freely than the cumbersome ships.

A few of the buoys sent off their wave-height data at once, by radio, to scientists in a PBM plane circling 10 or 15 miles away.

The last important date before B-Day was 19 July 1946, when the final rehearsal was held. It went

* *These instruments, powered by batteries, could only operate for limited periods and therefore had to be started almost at the last moment before the explosion. To make final adjustments on the starting mechanisms a number of picked men were kept aboard certain of the target ships until a few hours before Mike Hour. These men breathed a great deal easier when the small boats showed up on schedule to take them out of the lagoon.*

† *The echo sounder's main component is an underwater "transducer," or combination transmitter and receiver of sound waves in water. The transducer gives out a sudden pulse of sound, listens for the echo from the bottom, and measures the time interval before the echo is received. An increase in time interval corresponds to an increase in depth.*

through successfully. However, the weather was disappointing and much of the aviation program had to be cancelled; luckily a complete aviation rehearsal had been held separately a few days before.

The weather prediction for July 25, 1946, which was to be B-Day, was indecisive. Colonel B. J. Holzman and Captain A. A. Cumberledge (Navy), in charge of weather forecasting, studied and restudied the bulletins being sent in continually from weather reconnaissance planes, land stations, and surface vessels; by bad luck, a so-called tropical front lay almost exactly above Bikini Lagoon. But the odds appeared good that the front would move off slowly in favorable manner, and at 8:50 a.m. on July 24, Admiral Blandy made the decision to get the B-Day program underway.

Final inspections were made of target vessels, and final attentions were given to test animals and scientific instruments.

Then the evacuation began. The majority of the support ships quit the Lagoon by the evening before B-Day. The remainder left by 6:20 a.m. on the morning of B-Day. Among the last persons to leave the lagoon was a group consisting of Admiral Parsons, Dr. M. G. Holloway, Mr. R. S. Warner, Jr., and a few others. This group made the final adjustments aboard the bomb-carrying ship LSM-60, and quit her at 6:07 a.m. Just 148 minutes later, this ship ceased to exist.

Shortly before How Hour, Dr. M. G. Holloway on the CUMBERLAND SOUND periodically closed switches which sent to LSM-60 the successive coded signals preliminary to the actual firing on the bomb. Dr. E. W. Titterton counted off the final seconds; through loudspeakers the relentless toll was heard by the 42,000 men waiting outside the lagoon, and by radio listeners throughout the world.

The bomb detonated at 59.7 seconds after 8:34 a.m. on July 25, 1946, Bikini Local Time. This corresponded to roughly 4:35 p.m. on July 24, Eastern Standard Time and 9:35 p.m. on July 24, Greenwich Civil Time. The bomb was located at Latitude 11° 35′ 05″ North, and Longitude 165° 30′ 30″ East. Its position was well below the surface of the lagoon.

Things happened so fast in the next five seconds that few eyewitnesses could afterwards recall the full scope and sequence of the phenomena. By studying slow-motion films and analyzing the records caught by the thousands of instruments, the scientists eventually pieced together the full story.*

When the bomb detonated, it released almost exactly the same amount of energy as had been released in Test A, namely 1,000,000,000,000,000,000,000 ergs (10^{21} ergs), equivalent to about 20,000 tons of TNT.

* *Without question one reason why observers had so much trouble in retaining a clear impression of the explosion phenomena was the lack of appropriate words and concepts. The explosion phenomena abounded in absolutely unprecedented inventions in solid geometry. No adequate vocabulary existed for these novelties. The vocabulary bottleneck continued for months even among the scientific groups; finally, after two months of verbal groping, a conference was held and over thirty special terms, with carefully*

This energy was transmitted initially as thermal radiation, gamma radiation, neutron radiation, other nuclear radiations, and shock wave.

The thermal radiation was extremely intense during the first small fraction of a second; photographs taken from the air show the water brightly illuminated from beneath the surface. The region in which the light originated, called the underwater fireball or "gas bubble," rose rapidly to the surface and, still within the first small fraction of a second, burst through the surface to spearhead the upward shoot of the water column. Many observers failed to see any light at all, but the photographs taken with the Eastman high-speed cameras and the Fastax cameras show clearly the presence of a brilliant area atop the column during the first instant of its rise. The practical effect of the thermal radiation was, of course, almost nil.

The neutron radiation was of little immediate consequence. Nearly all of it was absorbed in the sea water; almost none reached even the nearest target vessels. A significant fraction of the neutrons was absorbed by the sodium in the water, thereby producing radioactive sodium (Na^{24}). Neutrons were heavily absorbed also by hydrogen, chlorine, and other elements found in sea water.

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drawn definitions, were agreed on. Among these terms were the following: dome, fillet, side jets, bright tracks, cauliflower cloud, fallout, air shock disk, water shock disk, base surge, water mound, uprush, after cloud. These terms are defined in later pages of this chapter.

The initial burst of gamma radiation was almost entirely absorbed in the sea water. But the *continuing* gamma radiation, produced by the fission products was of great importance, as we shall see in a later paragraph.

The shock wave in water was probably the most severe shock wave ever produced on earth. Water, being almost incompressible, forms an almost ideal medium for transmitting shock waves. The special underwater gages showed that the pressure very close to the bomb must have been far greater than 10,000 pounds per square inch. Even at ranges of one-fourth to one-half mile the pressure was hundreds or even thousands of pounds per square inch. At distances of two to three miles the pressure was still intense.

Throughout most of its course the underwater shock wave traveled at the speed of sound, which was roughly 3500 miles per hour, or about one mile per second. Very close to the bomb the velocity was even greater.

The underwater shock wave spread throughout the shallow lagoon as a rapidly expanding circle. Photographs taken from the air show this water shock disk clearly. But it did not grow entirely uniform; a variety of irregularities were observed. Coral heads on the lagoon bottom in some instances impeded the growth and in other instances reflected the shock wave towards the surface of the water where it out-cropped in peculiar pattern. The shock wave was reflected from the underwater portions of the target vessels, and peak pressure values measured just behind ships were definitely lower than pressures at the near sides of the ships. Ordinarily, the pressure values were not as great close to the surface of the water as they were at greater depth.

As the underwater shock wave struck the target ships, it delivered terrific blows. A peak pressure of, say, 1000 pounds per square inch produces a total force of nearly a *million tons* on the underwater hull of a large warship situated broadside.

The underwater shock wave spread not only outward but also upward. In fact, it was the upward sweep which produced the most unprecedented effect. The upward sweep of the shock wave and fireball "gas bubble" reached the surface of the lagoon within a few hundredths of a second. As the gas bubble approached the surface, it produced a swelling called the dome. The dome was, of course, illuminated from within; and atop the dome rode the LSM-60. The dome now burst, and the fireball and water column leaped upward from the lagoon.

At about this instant, LSM-60 was blown to bits and sprayed upward with the column. If the column could be called a jet, LSM-60's departure was about the ultimate in jet assisted take-offs. If LSM-60 ever sank, it was as a fine rain of steel fragments and dust. No large fragment of her was ever found.

Observers could scarcely follow the lightning ascent of the column. Its upward rise was initially at a rate greater than a mile per second. Almost at once the rate decreased sharply; the growth was very slow after the first five seconds. The altitude reached at the end of fifteen seconds was about one mile; at the end of the first minute, the altitude was about one and one-half miles.

The rising mass of water passed rapidly from the "hair-do" stage to the crowned funnel stage and finally to the full cauliflower stage. Judging from photographs taken from drone planes flying directly above, the cauliflower appeared to have a relatively hollow center. The diameter of the cauliflower sixty seconds after Mike Hour was greater than one and one-half miles. The diameter of the column or stem itself was roughly 2000 ft.

Rising in the column were various fragments, presumably from LSM-60 but possibly from the lagoon bottom. Several of the larger fragments left in their wake white condensation trails, called bright tracks. A number of the fragments struck the surface of the water roughly a mile away.

Great black blotches appeared in the side of the column. One blotch was as large as a battleship. The cause of these blotches is not known with certainty. One theory is that they consisted of dust and soot sucked up from the target vessels. The largest of the big dark areas, which appeared near the location of the ARKANSAS, may not have been a true blotch at all; perhaps it was a cavernous hole in the side of the column. In other words, it may have been a "shadow" produced in the upward-sweeping water by the relatively immovable ARKANSAS.

It is estimated that the column contained several million tons of water. Early guesses were that ten million tons were tossed up, but later computations suggest that two million tons may be a more accurate figure. This amount of water would fill a swimming pool about twenty feet deep and nearly half a mile in diameter.

But the column was far from being solid water; actually it was about 99 percent air. A shell fired from a large gun could probably have passed straight through the column with little difficulty. Probably the water was more or less concentrated in the outer part of the column, with the center relatively empty. Some scientists believe that if suitable lighting had been provided inside the column, a person flying directly above could have peered down as far as sea level, and possibly even down to the very bottom of the lagoon itself.

The column wall was not smooth, but was inlaid with thousands of separate spikes, or column side jets, each as large as a destroyer. As the cauliflower approached maturity, these side jets began to fall. More and more their points turned downward to form a white cascade thousands of feet high. This falling curtain gathered speed, carrying with it thousands of tons of air in the cylindrical plunge back into the lagoon.

SHOCK WAVES

While the column was spurting upward, two kinds of shock waves were racing outward. The underwater shock wave, described on a preceding page, traveled fastest, and did the greatest damage. The shock wave in air was less harmful, but was extremely interesting in many respects. It had, for example, a dual origin. In part it was created by the very rapid expansion of the fireball and column in their first instant of escape from the water. The shock wave created, shaped like an egg standing on end, was so intense that it showed up clearly in short-exposure pictures taken from the towers on Bikini Island. The concentration of air in the shock wave acted like a prism and, by optical refraction, left a clear elliptical line on the photographic films. The shock wave in air was born also from the fillet, the circular region surrounding the column base. In the fillet area, the water was so violently hammered from below that the surface of the lagoon was pushed up slightly. The energy within the water could not be constrained to stay there; part of the energy leapt into the air to produce an air shock wave proceeding more upward than outward.

The combination of the elliptical shock wave and the upward shock wave produced a wave of remarkable shape. Where the two effects joined, the shock wave had a definite bend, such as occurs where the brim of a hat joins the crown. The bend did not last long. As the shock wave expanded, it smoothed out the bend and in short order assumed nearly hemispherical shape.

Both the underwater shock wave and the air shock wave left their circular marks on the surface of the lagoon. The water shock disk expanded very rapidly; the air shock disk expanded more slowly and showed up more clearly in the photographs.

The shock wave reflection effects were remarkably vigorous. Slow-motion pictures show the strange patterns produced on the surface by the underwater reflection of the water shock wave. They show also the typical effect produced when the air shock wave struck one of the inner ships: the localized reflection created a new spherical wave spurting out in many directions. Actually, it was not the secondary shock wave itself which was photographed, but the secondary condensation cloud which was pursuing the secondary shock wave.

The primary condensation cloud was tremendous, covering an area of roughly six square miles. It had started forming within one second of Mike Hour; one or two seconds later it had reached the "birthday cake on a platter" stage. But it evaporated very rapidly. Within eighteen seconds after Mike Hour it had the form of a hollow ring, and almost immediately thereafter it broke up and disappeared. A small condensation cap formed momentarily directly above the cauliflower; it lasted only a few seconds.

BASE SURGE

The base surge was an awesome yet deceptive phenomenon. It looked like a great wave of water. Actually it was a rolling mass of fluffy spray, mist, and air. It was not formed by the explosion proper, but as an indirect after-effect. The millions of tons of water thundering back into the lagoon created an enormous volume of spray and mist, which billowed outward from the column base. The outward velocity of this diffuse mass was initially more than fifty miles per hour; later it slowed to twenty-five miles per hour. As the base surge spread out, it resembled a steadily expanding and fattening doughnut. At first, its height was about 300 ft. — a mere three times the height of a battleship's mast; later it reached 1000 ft., and ultimately towered to 2000 ft.

The base surge, for all its tenuousness, left a kiss of death on the majority of the target vessels. The white billows carried radioactive fission products equivalent to many tons of radium. Gamma radiation issued in all directions. The base surge did not merely pass by the ships; its radioactive mist settled on the deck, moistened every bit of exposed metal, wood, and canvas. Even after the moisture evaporated, radioactive residues remained. And always the deadly gamma radiation continued; persons remaining within its reach would have been doomed. The radius of action is especially great downwind, since the surge tends to drift in that direction. The base surge is the newest menace wrung from within the atomic nucleus.

WATER WAVES

Water waves were another type of unleashed fury. When the millions of tons of water were ripped from the lagoon, an enormous cavity was produced, extending probably to the very bottom of the lagoon. Almost immediately the surrounding water rushed madly to fill the cavity; actually, it over-filled the cavity and produced a great mound. The mound then sank slowly to the normal level of the lagoon. This rapid dying off of the central oscillation in the water probably constituted the first experimental verification of the complicated mathematical theory (Cauchy-Poisson equation).

From the birth and death of the giant mound, the water waves were formed — majestic waves higher than had ever before been produced by man and perhaps greater than Nature herself ever raised.* No one knows how great the waves were near the Zeropoint, or whether there actually was inside this cauldron anything that could properly be called a wave. But near the edge of the column, say 1000 ft. from the Zeropoint, the waves were very real. Photographs show that the highest wave was eighty to one hundred ft. from trough to crest. The wave heights were in

** Possibly greater waves were produced when, in 1883, the island of Krakatao exploded.*

almost perfect agreement with predictions made before the tests. These predictions were based on small scale experiments made by the Oceanographic Group at the United States Naval Electronics Laboratory, San Diego, California, and the Naval Mine Warfare Test Station at Solomons Island, Maryland. The explosive charges used in those experiments contained TNT and weighed from one to 2000 pounds.

The first wave, the highest of all, contained several million tons of water. It traveled with a speed of the order of fifty miles per hour, which is just what the wave experts had predicted.*

At the start of its outward travel, the first wave was in unstable condition; its crest tended to get ahead of its base. The result was what oceanographers call a spilling breaker. But as the wave moved along, its height diminished and it lost its tendency to break.

The first wave soon found itself less high than the second wave; and a little later the third wave claimed pre-eminence. This handing down of the honors from one wave to the next was in full accord with the expectations of the oceanographers, who say that the *group* velocity is less than the *phase* velocity.

* *The prediction made by Commander Roger Revelle and Dean M. P. O'Brien was based on the known depth of the lagoon and on the rough rule that in shallow water of specified depth all very long waves have the same velocity. Knowing the depth, they could compute the velocity. In really deep water, of course, the situation is entirely different: a wave's velocity depends on its length, long waves traveling faster than short ones.*

The waves multiplied as they progressed. Near the column there were few of them, but as they approached Bikini beach, they were a family of fifteen or twenty. Each wave gathered height as it entered the shallow water off Bikini, three and a half miles from the Zero-point; it drew itself up into a short, steep, plunging breaker. Maximum height of the breakers was fifteen feet.

The uprush was not particularly severe. The water rushed up over the beach top, in many areas, and caused some flooding and erosion. Thousands of tons of beach materials were moved. Several medium-sized beach landing craft and small boats were damaged and a few huts also. But no noteworthy damage resulted.*

The "backrush" from the first wave swept more than 50,000 tons of beach sand into the lagoon.

The explosion produced much erosion of the lagoon floor directly beneath the bomb. The amount of bottom material wrenched free was of the order of a million cubic yards. The main crater formed was not entirely

** Maximum water height on Bikini Island was measured by two kinds of height gages: tin-can gages and electrical-fuse gages. The tin-can gage consists merely of a tall pole securely mounted vertically and carrying a number of tin cans at various heights. Each can is upright; it is open at the top and has a small awning to keep out the rain. If a wave covers the ground to a depth of, say, four feet, then all cans below the four-foot level are filled with water. In the electrical-fuse gage, the tin cans are replaced by wires having small gaps. When the water rises enough to immerse a gap, an electrical current flows and a small electrical fuse is blown out. From inspection of the assembly of fuses, maximum water height can be determined easily.*

smooth, but was found to contain several secondary craters.*

The majority of the materials torn out settled to the bottom within a few hours, forming a thick structureless carpet. But thousands of tons of sediment remained in suspension. Even after two weeks, the water still carried a mineral load. Some bottom material had been thrown high into the air; some of it fell onto the decks of target vessels.

A large number of fish were killed in the corner of the lagoon where the explosion occurred. Elsewhere in the lagoon the fish survived, and outside the atoll the fish were practically unaffected either by the explosion or the subsequent radiological effects.†

* *The depth of the bottom crater was computed from very accurate soundings made before and after the explosion. The soundings were made by members of the Oceanographic Group operating from the hydrographic survey ship BOWDITCH. An ingenious but unsuccessful attempt was made to measure the exact diameter of bottom area laid bare by the explosion. Some days before the explosion, the Group laid long steel cables on the bottom near the Zeropoint, and to these cables they attached a large number of hollow steel cylinders containing unexposed photographic film. It was expected that in those areas where the water was swept clear, gamma radiation from the underwater fireball would reach the cylinders and affect the film. Unfortunately, the explosion was so violent that none of the cylinders were ever seen again.*

† *Over 40,000 atoll fish were caught. Several new types were found. Professional fishermen recruited from the west coast fishing industry caught many tons of tuna and other deep sea fish (pelagic fish). Unfortunately, 98 percent of these latter were lost when YP-636 went aground thirty miles south of San Francisco in September, 1946.*

A strong earth shock was recorded by seismographs located on Amen, eight miles from the Zeropoint.

DAMAGE TO SHIPS

The B-Day Bomb sank nine ships and seriously damaged many others.

LSM-60, situated directly above the bomb, disintegrated instantly. A few of the flying fragments were photographed by tower motion picture cameras; a very few fragments fell on other vessels and were later picked up by boarding personnel.

The 26,000 ton battleship ARKANSAS sank almost at once, while still obscured by spray and steam. She was the closest of the target vessels and was located well over 500 feet from the Zeropoint. She suffered severe damage to her hull. In sinking, she carried with her the dubious honor of being the first battleship to be sunk by an atomic bomb, and the first battleship to be sunk by a bomb which never touched her.

The aircraft carrier SARATOGA sank by the stern seven and a half hours after Mike Hour. She was the next-to-closest of the target ships and was located over 500 ft. from the Zeropoint. Although she was designed over 20 years ago and, before she sank, was the oldest United States aircraft carrier afloat, she was extremely strongly built. In fact her hull had been designed originally as that of a battle cruiser, and included hundreds of watertight compartments. She weighed 33,000 tons. By three hours after Mike Hour, her stern was clearly low in the water and she had begun to list slightly to starboard. By five hours after Mike Hour her freeboard had decreased further, and observers indulged in some betting as to whether she would sink, and when. Admiral Blandy ordered tugs to attempt to secure lines to her if practicable and tow her to Enyu Island for beaching. But this proved to be impossible. The ship herself and the water surrounding her were too "hot" to permit safe approach. She sank slowly. Her stern was awash at 3:59 p.m. By 4:09 p.m. her deck was completely awash and air could be seen blowing from her. The last bit of her superstructure sank forever beneath the surface of the lagoon at 4:16 p.m. Analysis of photographs of "Old Sara" shows that all moored airplanes and materials on her deck had been swept overboard; much of her superstructure had been demolished; her distinctive stack had crashed to the flight deck and her below-the-waterline hull had taken a serious beating.

The ex-Japanese battleship NAGATO sank during the night, four and a half days after Mike Hour. Only a few hours after Mike Hour she took on a list of about 5 degrees. This list increased so slowly that many observers expected her to survive. When her characteristic silhouette failed to show itself on the morning of July 30, surprise was general. No one had seen her sink. Undoubtedly openings had been made in her hull.

Three of the submarines sank. They were the PILOTFISH, SKIPJACK, and APOGON. All of these were in submerged position when the explosion occurred. Air bubbles and fuel oil escaped from the APOGON as she went down.

YO-160, a concrete oil barge, was seen in photographs taken immediately after the explosion, but she sank quickly. LCT-1114, a 120-ft. landing craft, capsized and was later sunk.

Besides sunken ships, there were many seriously damaged ships to bear witness to the power of the underwater explosion. Serious damage was done to the battleships NEW YORK and NEVADA, the cruiser PENSACOLA, the destroyers HUGHES and MAYRANT, the APA's FALLON and GASCONADE, and LST 133. The HUGHES was soon found to be in sinking condition, and the FALLON listed badly. Both of these ships were therefore taken in tow and beached.

Damage was caused principally by the underwater shock wave, which tended to crush ships' hulls and seriously jar internal machinery. The pressure wave in air was severe also, but was responsible ordinarily only for less serious damage to superstructures. The towering waves of water shared in the production of damage. It also tended to move some of the ships bodily, outward from the Zeropoint.

INJURY TO ANIMALS

Because the target ships were so radioactive, Captain Draeger's men were for several days unable to

UPPER. Last resting place of the Test B bomb was a sturdy steel caisson slung at predetermined depth beneath LSM-60. At exactly 8:35 a.m. on July 25, 1946, bomb, caisson, and ship ceased to exist. LOWER. A shimmering hemisphere, the condensation cloud, springs into being, shrouding the target area.

Plate 25

This photograph was taken by an automatic camera mounted in a drone plane flying directly above the Zero-point at the instant of detonation, a remarkable achievement in drone control. The cauliflower is funnel-shaped at this stage; within its jagged rim is a condensation cloud nearly a mile in diameter, which evaporated a few seconds later.

In this oblique view the condensation cloud, still in an early stage, is expanding on the heels of the air shock wave at over 700 miles per hour. A large ship appears as a tiny black speck in the air shock disk, the white area marking the outward sweep of the shock wave across the surface of the water.

Plate 26

UPPER. The Test B column, containing two million tons of water, rises in wrath. It towers above the ex-Japanese battleship NAGATO and a large floating drydock. LOWER. Seconds later the great column thunders back into the lagoon, unleashing the billowing base surge, 500-ft.-high wall of spray and mist.

Plate 27

This photograph, perhaps the most awesome of all, shows the cauliflower aftercloud looming darkly overhead, the mile-high column now fast collapsing, and the base surge plunging towards the NAGATO (left) and NEVADA (right). Fission products equivalent to hundreds of tons of radium infest the area.

Plate 28

UPPER. Drawing itself up to a height of 15 feet, the first wave produced by the underwater explosion pounds Bikini beach. Note the height-of-water marker pole. LOWER. Backrush from the waves carried 50,000 tons of beach sand into the lagoon. Note erosion visible at right, and the sand-filled boat.

Plate 29

The aircraft carrier SARATOGA is sinking by the stern, seven hours after the Test B explosion. She was more than 500 feet from the Zeropoint, yet her below-the-waterline hull took a bad beating; much of her superstructure including her stacks had been demolished, and all moored airplanes and materials on deck had been swept overboard.

A Navy fireboat washes down the deck of the battleship NEW YORK after Test B. This procedure was followed for many of the target ships prior to sending inspection parties aboard, since great quantities of radioactive water had been thrown onto the decks. A few of the ships remained "hot" for months.

Plate 30

A number of fish caught after Test B were found to be radioactive. By placing them overnight on photographic films, radioautographs were obtained, as of the surgeon fish shown here. Radioautographs were obtained of "hot" algae also. Biological processes have, of course, no effect on radioactivity.

The fourteen ships sunk in the operation carried down with them much valuable information, such as instrument records and various types of damage to ship structures. Divers and underwater cameras made good a large part of the informational gap. Here is an underwater photograph of superstructure wreckage, including a damaged pressure gage.

Plate 31

UPPER. Dr. G. K. Green, of the Army Ground Group, studies a telemetered chart made by an Esterline Angus recorder on AG 76 AVERY ISLAND. LOWER. Composite photograph roughly comparing the Test B cauliflower cloud with New York skyscrapers. An exact comparison would be even more extreme. The cauliflower cloud, nearly two miles in diameter, would overshadow a considerable portion of Manhattan. It requires little study to appreciate catastrophic destruction.

Plate 32

approach the ships on which the test animals were located. Fortunately this situation had been allowed for in advance: the animals had been given sufficient food and water to last for at least ten days. In fact all surviving animals had small supplies of food remaining at the time the ships were reboarded.

The animals were found to have suffered very little from shock, and of course, none from heat or light.

But radioactivity took a heavy toll. Some of the animals had died from radioactivity even before the ships were reboarded. Many others died later. All the pigs died as a result of exposure to nuclear radiations. Many rats died from the same cause, but a number were still alive in late September, 1946.

As before, exposure to gamma radiation produced a variety of symptoms, including general apathy, weakness, and tendency to develop secondary infections. But it should be remembered that radiation sickness is essentially painless; and in the case of animals, victims have no mental anguish such as would presumably assail human beings. The animal languishes and either recovers or dies a painless death. Suffering among the animals as a whole was negligible. By studying them we have gained knowledge as to what dangers might confront men and what steps would minimize the injury.

The degree of radioactive poisoning of water and ships was impressive. The total amount of radioactive materials released was initially equivalent to hundreds of tons of radium. Some of the radioactive material drifted off in the cauliflower cloud; but much remained in the lagoon area. The base surge, in its precipitant flight outward from the column, carried radioactive materials. It drenched the target vessels and left them radioactively poisoned.

Over 90 percent of the target vessel array fell victim to radioactivity. The extent of radiological hazard went beyond what had been expected.

Without question, ships' crews would have been seriously affected over a wide area. Had the target array been manned, casualties and both physical and psychological injury would have been very great. Rescue and attention to casualties would have been difficult and dangerous. Within 2000 yards of the explosion center, ships would probably have been inoperative and a lapse of weeks might well have ensued before relatively undamaged ships could again have been used in combat.

TERMINATION

It was several days before the majority of the target vessels could be reboarded. Not until ten days after B-Day was it feasible to reboard all the vessels. The radioactivity of the ships was more severe than had been expected.

The lagoon itself was re-entered a few hours after the explosion. The first boats to approach the target array were the unmanned drone boats, controlled by radio signals sent from support ships located well out of danger. These boats threaded their way through the array of "hot" ships, taking water samples and recording just how intense the radioactivity was in each area. Manned boats skirted the region cautiously, keeping outside of the really "hot" zones.

Master charts were prepared on the support ships showing danger areas. A "red line" was drawn showing where the radioactivity exceeded one roentgen per day, and was thus unsafe. A "blue line" indicated where the activity was less than 0.1 roentgen, and was safe. As the lagoon currents slowly spread, shifting the contaminated water area, new charts were prepared and word sent to all ships.*

All animals had been taken off the target ships by five days after B-Day; some of the scientific instruments could not be approached with safety for weeks afterwards.

* *Re-entry of the target area would have been greatly slowed if previous studies of lagoon currents had not been made. Commander Roger Revelle's Oceanographic Group, besides making model studies, had spent weeks finding just where the lagoon currents went, and how fast. With dye markers, floating poles, and other equipment his group tracked not only the surface currents but also the counter-currents flowing along the lagoon bottom. They found where the bottom water welled up, and where the surface water descended. They found how the current changed with wind and tide. Thanks to this information, they could assure the Task Force Commander that advance scouts would not suddenly find themselves trapped by radioactive water welling up behind them unexpectedly.*

Decontamination measures were initiated promptly by Admiral T. A. Solberg. A number of different methods were used in this newest of problems: removing radioactive materials from ships' decks, sides, superstructures. Streams of water were played on the ships; special chemicals were applied; strenuous scrubbing was tried. The success of these methods varied widely.

Despite all efforts, radioactive contamination continued to be a major problem for many weeks. Some of the ships, veritable radioactive stoves, were towed to Kwajalein. Some contaminated ships were later towed to Pearl Harbor and continental United States to permit more convenient study of decontamination methods and also to permit training personnel in radiological safety and decontamination processes.*

Even some of the support ships found that their salt water lines and evaporators became contaminated

** In late August of 1946, Captain G. M. Lyon, Safety Adviser, was requested by the Task Force Commander to set up a Radiological Safety School to train officers in all phases of radiological safety. Commander D. L. Kauffman was placed in charge of the School. First classes began on September 9, 1946, and the students included roughly 100 officers from Army Air Forces, Army Ground Forces, Navy, Marine Corps, and the United States Public Health Service. The training program included a four-weeks academic course in Washington, D. C., followed by three months of practical instruction in the field. The faculty of the school included initially: Lt. Col. A. Roth of the Army Ground Forces, Lt. Col. J. M. Talbot, of the Army Air Forces, Comdr. E. G. Williams, of the United States Public Health Service, Dr. G. Dessauer of the University of Rochester, Dr. R. J. Stephenson of Wooster College, and Dr. M. L. Pool of Ohio State University.*

by the radioactive lagoon water. Being well clear of the lagoon at the time of the explosion did not prevent these ships later feeling the effects of the bomb.

A number of the support ships, on reaching the west coast of the United States, were found to be still affected by radioactive materials, and were held in temporary quarantine. Strenuous processes of cleaning and decontamination were arranged. Special methods of cleaning the sides and bottoms of the ships were worked out; oxygen rebreathing apparatus was supplied to the men doing the work; elaborate checking procedures were established.

Fortunately, no hazard existed to personnel not actively engaged in the operation, repair, or cleaning of the contaminated portions of the ships. This meant that there was no danger to anyone from having these ships in harbors and at ordinary docking facilities. By observing relatively simple safety precautions, personnel working on these ships did so with no danger to themselves.

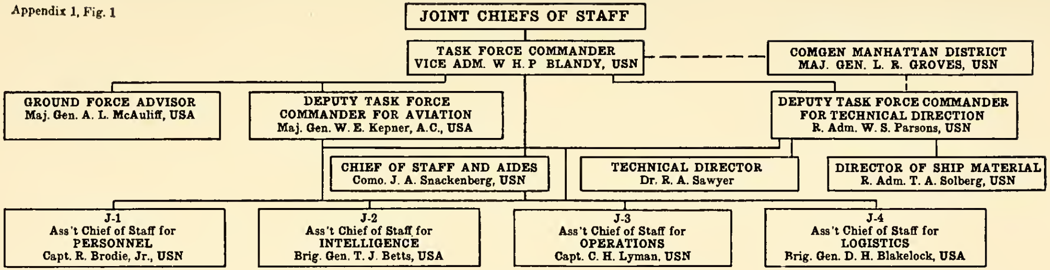
The homeward voyage of the support vessels from Bikini got underway in early August. Few support ships remained in the atoll after mid-September. The scientists gathered again in their laboratories in continental United States, analyzed their instruments' records and wrote their detailed reports. Then the overall reports were compiled. For the first time the full story of what happened at Bikini began to unfold. Now, armed with facts instead of guesses, engineers and strategists could proceed with their planning for a national defense geared to the Nucleonics Age.

The Joint Task Force was dissolved on November 1, 1946, by the Joint Chiefs of Staff. Final activities were carried on thereafter by a Joint Crossroads Committee, of which Rear Admiral W. S. Parsons was made Chairman. It is the task of this Committee to see that all possible information is gleaned from the Operation. Years may elapse before the books may be closed and the Operation allowed to settle itself into its niche in History.

Appendix 1

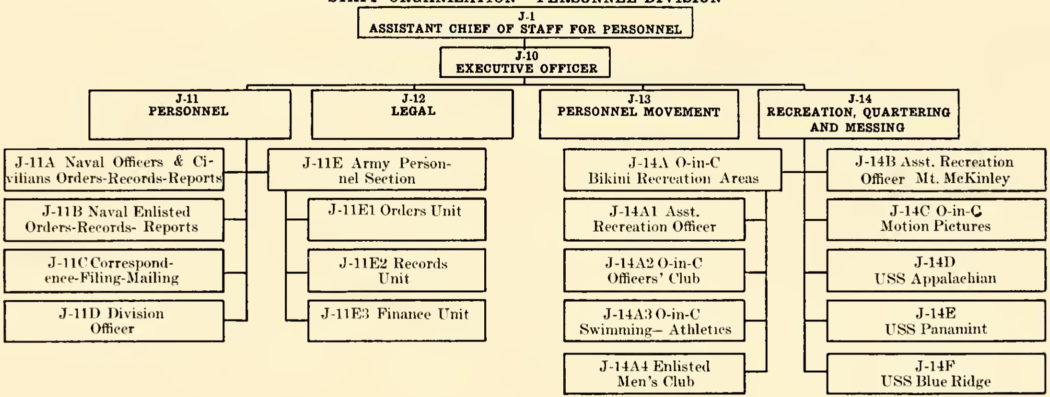
ORGANIZATION CHARTS

Appendix 1, Fig. 1



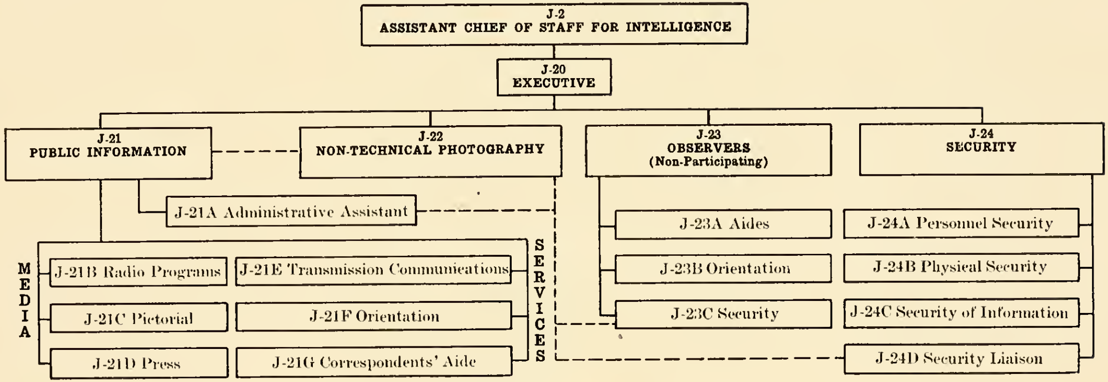
Appendix 1, Fig. 2

JOINT TASK FORCE ONE
STAFF ORGANIZATION—PERSONNEL DIVISION



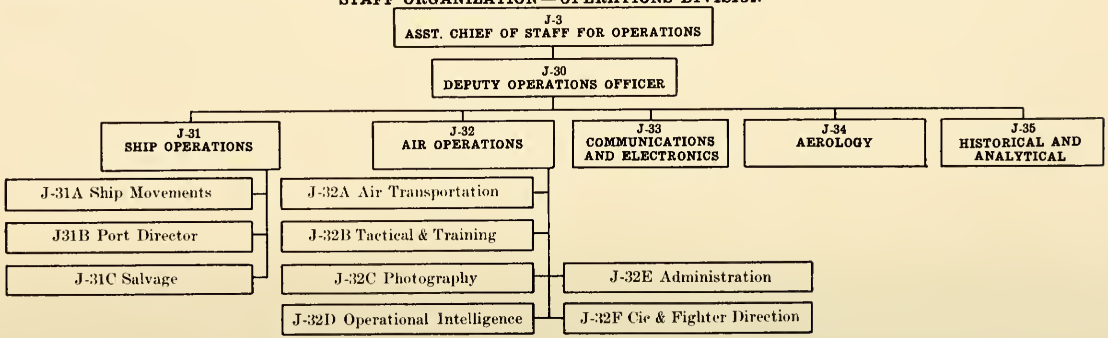
Appendix 1, Fig. 3

JOINT TASK FORCE ONE
STAFF ORGANIZATION INTELLIGENCE DIVISION

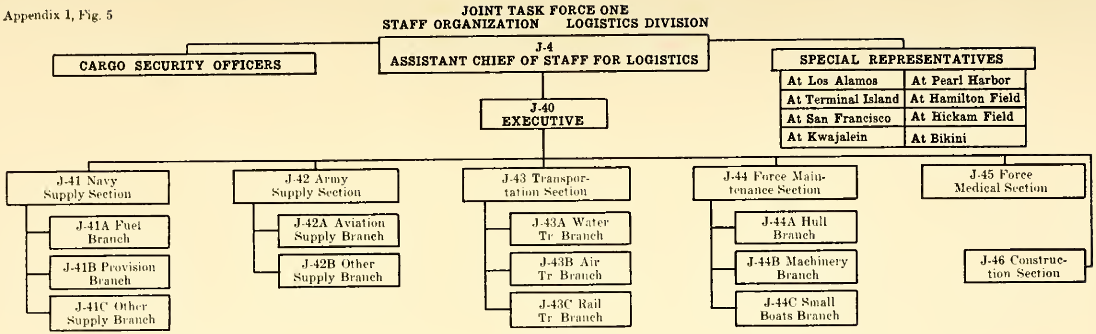


Appendix 1, Fig. 4

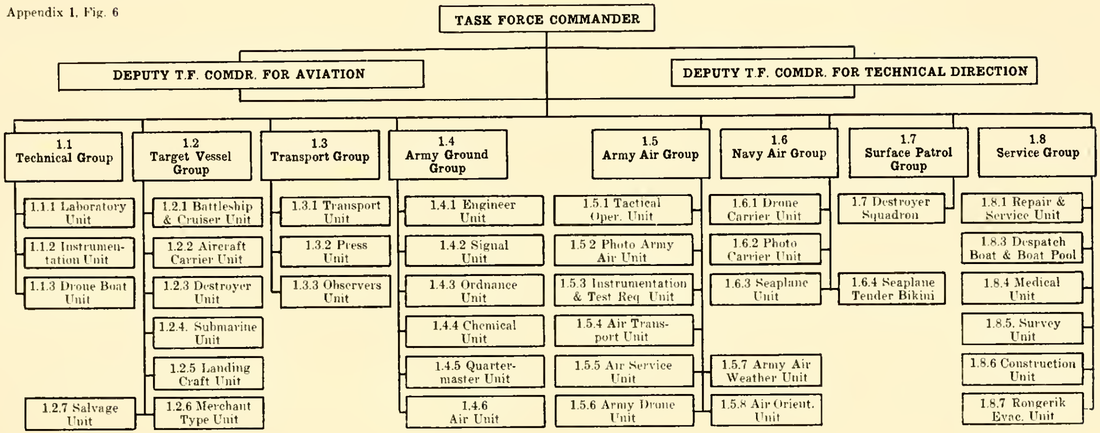
JOINT TASK FORCE ONE
STAFF ORGANIZATION—OPERATIONS DIVISION



Appendix 1, Fig. 5



Appendix 1, Fig. 6



Appendix 2

List of Principal Participating Officials

Vice Admiral W. H. P. Blandy, Commander of Joint Task Force One, was assisted by a staff including two Deputy Task Force Commanders and a Ground Forces Adviser.

Rear Admiral W. S. Parsons, Deputy Task Force Commander for Technical Direction, was assisted by a technical staff including the following:

- Four special assistants:
  - Dr. John von Neumann, Scientific Adviser
  - Capt. F. L. Ashworth (Navy) Assistant for Aviation
  - Capt. Horacio Rivero (Navy) Assistant for Special Projects
  - Dr. W. A. Shurcliff, Historian
- Two technical administrators:
  - Dr. R. A. Sawyer, Technical Director
  - Rear Admiral T. A. Solberg, Director of Ship Material
- Two technical advisers:
  - Capt. G. M. Lyon (Navy), Safety Adviser
  - Col. S. L. Warren, Radiological Safety Adviser

Major General W. E. Kepner, Deputy Task Force Commander for Aviation, was assisted by Army and Navy officials including the following:

- Brig. Gen. T. S. Power, Assistant Deputy Task Force Commander for Aviation
- Capt. H. D. Riley (Navy), Assistant for Naval Aviation

Major General A. C. McAuliffe, Ground Forces Adviser, was assisted by Col. J. D. Frederick and others.

CHIEF OF STAFF

Commodore J. A. Snackenberg, Chief of Staff of Joint Task Force One, was assisted by four assistant chiefs of staff for personnel, intelligence, operations, and logistics.

Captain Robert Brodie, Jr. (Navy), Assistant Chief of Staff for Personnel, was assisted by Comdr. C. A. Powell, Lt. Comdr. H. B. Williams, Lt. M. S. Ochstein (Navy), Lt. (jg) John J. Babinski (Navy), and Lt. A. J. Meyer (Navy).

Brigadier General T. J. Betts, Assistant Chief of Staff for Intelligence, was assisted by a staff including the following:

Captain Fitzhugh Lee (Navy), Head of the Public Information Section

Captain R. S. Quackenbush (Navy), Head of the Non-Technical Photography Section

Colonel H. B. Smith, Head of the Nonparticipating Observers Section

Commander Charles Randall, Head of the Security Section

Captain C. H. Lyman, Assistant Chief of Staff for Operations, was assisted by a staff including the following:

Capt. W. C. Winn (Navy), Head of the Ship Operation Section

Col. W. D. Ganey, Head of the Air Operation Section

Capt. K. M. Gentry (Navy), Head of the Communications and Electronics Section

Col. B. J. Holzman, Head of the Aerology Section (Working closely with him was Capt. A. A. Cumberledge (Navy))

Capt. A. B. Leggett (Navy), Head of the History and Analytical Section

Brigadier General D. H. Blakelock, Assistant Chief of Staff for Logistics, was assisted by a staff including the following:

Capt. M. A. Norcross (Navy), Head of the Executive Section

Comdr. M. H. Gatchell, Head of the Navy Supplies Section

Col. F. W. Ott, Head of the Army Supplies Section

Col. A. D. Higgins, Head of the Transportation Section

Comdr. J. J. Fee, Head of the Force Maintenance Section

Capt. W. E. Walsh (Navy), Head of the Force Medical Section

Comdr. K. C. Lovell, Head of the Construction Section

TECHNICAL DIRECTOR

Dr. R. A. Sawyer, Technical Director, was assisted by a large technical staff including six immediate assistants, and ten administrators. The six immediate assistants were:

Dr. E. W. Thatcher, Deputy Technical Director

Capt. F. L. Riddle (Navy)

Comdr. E. S. Gilfillan

Comdr. A. W. McReynolds

Lt. Comdr. J. K. Debenham

Lt. (jg) J. A. Young

Ens. H. M. Archer

The ten administrators were as follows:

Dr. W. G. Penney, head of the Pressure Group (Cans and Drums).

Comdr. Roger Revelle, Head of the Oceanographic Group. Assisting him in the direction of the oceanographic survey work were Lt. Comdr. C. A. Barnes and also Lt. Comdr. J. R. Lyman, Lt. Comdr. M. C. Sargent, Capt. M. A. Traylor (Army), assisting in the direction of wave measurement work were Lt. Comdr. F. G. Morris and also Mr. N. J. Holter, Comdr. Beauregard Perkins, Jr.

Comdr. C. H. Gerlach, head of the BuShips Instrumentation Group. Principal assistants were Comdr. R. M. Langer, Lt. Comdr. L. S. Beedle, Lt. Comdr. F. J. Dellamano and also Mr. E. E. Johnson, Dr. G. E. Hudson, Dr. Irwin Vigness, Mr. P. J. Walsh, Mr. H. E. Jensen, Mr. C. F. Kasanda, Mr. F. J Friel.

Capt. C. L. Engelman (Navy), head of the Electronics Group. Principal assistants were Dr. T. D. Hanscome, Comdr. J. L. Miller, Comdr. J. E. Rice, Comdr. J. G. Houpis, Dr. D. G. Fink, Comdr. F. X. Foster, Lt. Comdr. R. L. Reaser, Lt. Lawrence Bershad (Navy).

Col. S. L. Warren, head of the Radioactivity Group. Principal assistants were Col. A. A. deLorimier, Capt. R. J. Buettner (Navy), Comdr. D. L. Kauffman, Dr. Herbert Scoville, Jr., Dr. Joseph Hamilton, Dr. Kenneth Scott, Dr. Gerhard Dessauer, Dr. Lauren Donaldson, Mr. Donald Collins.

Capt. A. E. Uehlinger (Navy), head of the BuOrd Instrumentation Group. Assisting him were Dr. G. K. Hartmann, Capt. L. W. McKeehan (Navy), Lt. Comdr. F. L. Yeo, Dr. C. W. Lampson, Dr. A. B. Arons, Dr. J. V. Atanasoff, Comdr. S. S. Ballard, Dr. J. E. Henderson, CWO J. P. Orr.

Dr. M. G. Holloway, head of the Los Alamos Group. Assisting him were Mr. R. S. Warner, Jr., Dr. N. N. Nereson, Dr. G. A. Linenberger, Dr. William Rubinson, Dr. J. L. Tuck, Dr. B. Brixner, Dr. J. Wieboldt, Dr. J. Wiesner, Dr. H. Weiss, Dr. J. Hirshfelder.

Comdr. George Vaux, head of the Remote Measurements Group.

Capt. R. S. Quackenbush (Navy), head of the Technical Photograph Group. Principal assistants were Comdr. J. H. McElroy, Col. P. T. Cullen, Comdr. K. S. Shaftan, Dr. Brian O'Brien, Lt. F. Terzo (Navy), Dr. B. Brixner.

Col. D. F. Henry, head of the AAF Electronics Group.

DIRECTOR OF SHIP MATERIAL

Rear Admiral T. A. Solberg, Director of Ship Material, was assisted by a large staff including six special assistants and six group administrators. His six principal special assistants were as follows:

Capt. L. A. Kniskern (Navy)
Capt. F. W. Slaven (Navy)
Capt. F. X. Forest (Navy)
Comdr. E. H. Batcheller
Lt. Comdr. L. H. Roddis, Jr.
Lt. Comdr. L. R. Glosten

His six group administrators were as follows:

Col. J. D. Frederick, head of the DSM Army Group. Principal assistants were Col. J. S. Weber, Lt. Col. S. B. Smith, Capt. C. H. Wollenberg (Army), Lt. Col. S. F. Musselman, Capt. H. C. Adams (Army), Col. L. P. Jordan, Maj. E. K. Walters.

Capt. T. C. Lonnquest (Navy), head of the DSM Aeronautics Group. Principal assistants were Capt. J. E. Dodson (Navy), Comdr. J. K. Leydon, Maj. J. W. Morrison, Comdr. J. R. Reedy, Lt. E. V. Sizer (Navy), Lt. Comdr. G. V. Schliestett, Lt. Comdr. W. A. Hopkins, Lt. J. A. Torrey (Navy).

Capt. L. A. Kniskern (Navy) was originally head of the DSM BuShips Group; later Capt. F. X. Forest (Navy) was made head of the Group. Principal assistants were Capt. F. W. Slaven (Navy), Capt. R. C. Bell (Navy), Comdr. C. L. Gaasterland, Lt. (jg) J. F. DiStefano, Comdr. J. W. Roe, Capt. W. S. Maxwell (Navy), Capt. P. S. Creasor (Navy).

Capt. E. B. Mott (Navy) was head of the DSM Ordnance Group. Principal assistants were Comdr. A. A. Freedman, Capt. C. S. Piggott (Navy), Comdr. Edgar O'Neill, Comdr. F. W. Russe, Comdr. H. C. Dudley, Lt. Comdr. H. B. Taylor, Lt. Comdr. H. M. Tatum, Lt. Comdr. T. W. Johnson

Capt. G. M. Lyon (Navy) was head of the DSM Medical Group. Principal assistants were Capt. Oscar Schneider (Navy), Comdr. Marshall Cohen, Lt. Harry Browdy (Navy), Lt. (jg) A. L. Rogers, Lt. G. W. Morrison, Jr. (Navy), Lt. Comdr. J. J. McCoy; also Capt. R. H. Draeger (Navy), Capt. Shields Warren (Navy), Comdr. R. H. Lee, Comdr. J. L. Tullis, Lt. Comdr. R. E. Smith, Lt. Maynard Eicher (Navy), Capt. F. R. Lang (Navy), CPhM C. E. Wagner.

Capt. C. L. Engelman, head of the DSM Electronics Group. (See also electronics personnel listed under Technical Director's staff).

TASK GROUP COMMANDERS

The eight task group commanders were as follows:

R. Adm. W. S. Parsons, Technical Group, T.G. 1.1
R. Adm. F. G. Fahrion, Target Vessel Group, T.G. 1.2
Capt. W. P. Davis (Navy), Transport Group, T.G. 1.3
Col. J. D. Frederick, Army Ground Group, T.G. 1.4
Brig. Gen. R. M. Ramey, Army Air Group, T.G. 1.5
R. Adm. C. A. F. Sprague, Navy Air Group, T.G. 1.6
Capt. E. N. Parker (Navy), Surface Patrol Group, T.G. 1.7
Capt. G. H. Lyttle (Navy), Service Group, T.G. 1.8

REAR ECHELON

Principal Rear Echelon officials included:

Rear Adm. F. J. Lowrey, Commander of Rear Echelon
Capt. H. R. Carson (Navy), Chief of Staff
Col. G. W. Trichel, Ground Force Adviser
Col. R. C. Wilson, Commander for Aviation
Comdr. D. Klein, Commander for Technical Direction
Lt. Comdr. D. M. Rubel, Asst. Chief of Staff for Personnel
Comdr. K. Daly, Asst. Chief of Staff for Intelligence
Lt. Comdr. P. J. Hidding, Asst. Chief of Staff for Operation
Maj. W. H. Lollar, Asst. Chief of Staff for Logistics

Appendix 3

Joint Crossroads Committee

The Joint Crossroads Committee was created by the Joint Chiefs of Staff on November 1, 1946, to succeed Joint Task Force One, which went out of existence on that day.

The membership of the Committee was as follows:

Rear Admiral W. S. Parsons, Chairman
Brigadier General T. S. Power, Army Air Forces Member
Colonel C. H. M. Roberts, Army Ground Forces Member
Rear Admiral T. A. Solberg, Navy Member
Captain H. R. Carson (Navy), Executive Secretary

Supporting officials were as follows:

Captain F. L. Ashworth (Navy), Technical Assistant
Captain A. J. Bibee (Marine Corps), Photographic Files
Dr. E. S. Gilfillan, Technical Director
Major J. B. Gulley, Security
Commander D. L. Kauffman, Radiological Safety Instruction
Captain G. M. Lyon (Navy), Safety Consultant
Captain L. A. O'Brien (Army), Army Personnel
Captain Horacio Rivero (Navy), Technical Assistant
Lieutenant Commander J. D. Roche, Documentary Film
Dr. H. P. Scoville, Jr., Radiological Safety Reports
Dr. W. A. Shurcliff, Historian
Captain F. I. Winant, Jr. (Navy), Technical Assistant
Captain G. E. Zawasky (Marine Corps), Communications

Appendix 4

The Evaluation Board

The Evaluation Board was created by the Joint Chiefs of Staff. Its functions were (1) to be available for advising the Commander of Joint Task Force One in his planning of the tests, and (2) to prepare and present to the Joint Chiefs of Staff an evaluation of the results of the tests.

The complete membership of the Board, as announced on March 28, 1946, was as follows:

Dr. K. T. Compton, President of the Massachusetts Institute of Technology (Chairman)

Mr. Bradley Dewey, President of the American Chemical Society (Vice Chairman)

Mr. T. F. Farrell, New York State Department of Public Works, formerly Major General in the Manhattan Engineer District

General J. W. Stilwell, Commanding General, Sixth Army Area

Lieutenant General L. H. Brereton, on Special Duty in the Office of the Secretary of War

Vice Admiral J. H. Hoover, a member of the Navy General Board

Rear Admiral R. A. Ofstie, Senior Navy Member of the U. S. Strategic Bombing Survey

After General Stilwell's death, Lt. General A. C. Wedemeyer, Commanding General of the 2nd Army, was made a succeeding member.

The Board made careful study of the Operation Plan, and witnessed both tests. It observed Test A from an airplane located twenty miles from the Zeropoint. Four members witnessed Test B from an airplane eight miles from the Zeropoint, while the other three members were stationed on the hospital ship HAVEN, eleven miles from the Zeropoint. Detailed inspections were made of the target ships, and the technical reports were carefully studied.

The Board's final report, not yet completed, is expected to include conclusions on strategic, tactical, and technical matters pertinent to national defense. Preliminary reports, issued immediately after each test, are presented in this volume as Appendices 10 and 11.

Appendix 5

The President's Evaluation Commission

An Evaluation Commission was created by the President and given the function of (1) cooperating with the Secretaries of War and Navy in the conduct of the Tests, and (2) undertaking a study of the tests and submitting to the President a report of its observations, findings, conclusions, and recommendations.

The finally established membership, announced on March 30, 1946, was as follows:

- Senator C. A. Hatch, New Mexico (Chairman)
- Senator Leverett Saltonstall, Massachusetts
- Representative W. C. Andrews, New York
- Representative Chet Holifield, California
- Dr. K. T. Compton, President of the Massachusetts Institute of Technology
- Dr. E. U. Condon, Director of the National Bureau of Standards
- Mr. Bradley Dewey, President of the American Chemical Society
- Mr. W. S. Newell, President of the Bath Iron Works Corporation
- Mr. Fred Searls, Jr., special assistant to the Secretary of State

Members witnessed the tests from airplanes and surface vessels.

Brief reports, included here as Appendices 12 and 13, were made after each test.

Appendix 6

United Nations Observers

Each country having membership in the United Nations Atomic Energy Commission was invited to choose two observers. The observers actually attending were as follows:

Australia:	Commander S. H. K. Spurgeon, R.A.N.
Brazil:	Major Orlando Rangel (Army) Captain Alvaro Alberto de Motta y Silva (Navy)
Canada:	Air Vice Marshal E. W. Stedman Major General R. M. Luton (Retired)
China:	Chung-Yao Chao, Director of the Department of Physics, National Central University Major General Fisher Hou, Military Attache, Washington, D. C.
France:	Captain de Fregate Pierre Balande, General Staff (Navy) Mr. Bertrand Goldschmidt
Egypt:	Colonel Hassen Ragab, Military Attache, Washington, D. C. Lieutenant Colonel Abdel-Gaffar Osman, Chief Inspector of Explosives (Army)
Great Britain:	Flight Lieutenant F. Beswick, M.P., R.A.F. Commander A. H. P. Noble, M.P., R.N.
Mexico:	Mr. Juan Loyo Gonzalez Dr. Nabor Carillo
Netherlands:	Captain G. B. Salm, Head of Naval Intelligence Major H. Bruining, Ministry of Supply
Poland:	Mr. Stefan Pienkowski, President, University of Warsaw Mr. Anrzej Soltan, Head of Physics Department, University of Lodz
U.S.S.R.:	Dr. A. M. Mescheryakov, Head, Physics Department, University of Leningrad Mr. S. P. Alexandrov

Appendix 7

Congressional Observers

Immediately following the June 14, 1946, passage by Congress of House Joint Resolution 307 authorizing use of 33 United States combatant vessels as target vessels, invitations were extended to a number of Congressmen to witness the tests.

Thirteen Congressmen witnessed Test A and seven witnessed Test B. They were as follows:

Senators

Cordon, Guy, Oregon
Hatch, C. A., New Mexico
Hickenlooper, B. B., Iowa
Saltonstall, Leverett, Massachusetts

Representatives

Anderson, J. Z., California
Andrews, W. G., New York
Bates, G. J., Massachusetts
Bradley, M. J., Pennsylvania
Engel, A. J., Michigan
Gillespie, Dean M., Colorado
Holifield, Chet, California
Izac, E. V., California
Norrell, W. F., Arkansas
Rooney, J. J., New York

Appendix 8

Support Vessels

Ship	*Commanding Officer*
	(a) *Force Flagship* (carrying Vice Admiral W. H. P. Blandy, Task Force Commander)
MT. McKINLEY (AGC-7)	Capt. W. N. Gamet
	(b) *Target Vessel Control Group* (part of Task Group 1.2, commanded by Rear Admiral F. G. Fahrion)
FALL RIVER (flagship) (CA-131)	Capt. D. S. Crawford
	(c) *Technical Group* (Task Group 1.1, commanded by Rear Admiral W. S. Parsons)
ALBEMARLE (AV-5)	Capt. E. H. Echelmeyer, Jr.
KENNETH WHITING (AV-14)	Capt. A. R. Truslow, Jr.
CUMBERLAND SOUND (AV-17)	Capt. H. R. Horney
WHARTON (AP-7)	Capt. V. F. Gordinier
AVERY ISLAND (AG-76)	Comdr. D. E. Pugh
BURLESON (APA-67)	Capt. C. L. Carpenter
HAVEN (APH-112)	Capt. A. C. Thorington
BEGOR (APD-127)	Lt. Comdr. R. K. Margetts
LCT-1359	
LSM-60	Comdr. H. A. Owens
	(d) *Transport Group* (Task Group 1.3, commanded by Captain W. P. Davis (Navy))
GEORGE CLYMER (APA-27)	Capt. M. M. Bradley
BAYFIELD (APA-33)	Capt. J. C. Landstreet
HENRICO (APA-45)	Capt. J. B. Williams
APPLING (APA-58)	Capt. H. W. Howe
ROCKBRIDGE (APA-228)	Capt. W. H. Truesdell
ROCKINGHAM (APA-229)	Capt. G. P. Enright
ROCKWALL (APA-230)	Capt. C. H. Walker
SAINT CROIX (APA-231)	Capt. C. E. Carroll
BOTTINEAU (APA-235)	Capt. H. B. Edgar
BEXAR (APA-237)	Capt. C. C. Ray
ARTEMIS (AKA-21)	Comdr. M. E. Selby
ROLETTE (AKA-99)	Capt. M. Durski
OTTAWA (AKA-101)	Comdr. A. K. Ehle
APPALACHIAN (AGC-1)	Capt. J. B. Renn
BLUE RIDGE (AGC-2)	Capt. C. R. Criddle
PANAMINT (AGC-13)	Capt. W. B. Ammon
LST-817	Lt. (jg) J .A. Scott
LST-881	Lt. (jg) J. M. Scott

Ship	*Commanding Officer*
	(e) *Navy Air Group* (Task Group 1.6, commanded by Rear Admiral C. A. F. Sprague)
CV-38 SHANGRI-LA	Capt. W. D. Cogswell
CVE-117 SAIDOR	Capt. T. U. Sissons
AVP-49 ORCA	Comdr. J. D. Shea
DD-834 TURNER	Comdr. E. B. Rittenhouse
DD-835 C P CECIL	Comdr. W. Outerson
DD-882 FURSE	Comdr. C. J. Heath
DD-883 N K PERRY	Comdr. N. E. Smith
	(f) *Surface Patrol Group* (Task Group 1.7, commanded by Captain E. N. Parker (Navy))
DD-368 FLUSSER	Lt. Comdr. W. R. Laird
DD-692 A. M. SUMNER	Comdr. J. W. Howard
DD-693 MOALE	Comdr. R. P. Walker
DD-694 INGRAHAM	Comdr. F. A. Brock
DD-722 BARTON	Comdr. H. P. McIntire
DD-723 WALKE	Comdr. T. F. McGillis
DD-724 LAFFEY	Comdr. O. D. Waters, Jr.
DD-725 O'BRIEN	Comdr. H. E. Day
DD-770 LOWRY	Comdr. E. S. Miller
DD-781 R. K. HUNTINGTON	Comdr. M. Thompson
	(g) *Service Group* (Task Group 1.8, commanded by Captain G. H. Lyttle (Navy))
DIXIE (AD-14)	Capt. J. C. Goodnough
COASTERS HARBOR (AG-74)	Comdr. A. C. Harshman
CHICKASKIA (AO-54)	Capt. W. M. Searles
SEVERN (AO-(W)-61)	Capt. M. H. McCoy
ENOREE (AO-69)	Comdr. W. C. Cross
TOMBIGEE (AOG-(W)-11)	Lt. J. R. Davidson
POLLUX (AKS-4)	Comdr. D. A. Crandall
HESPERIA (AKS-13)	Comdr. H. B. MacLeod
AJAX (AR-6)	Capt. J. R. Clark
PHAON (ARB-3)	Lt. W. F. Horstkamp
TELAMON (ARB-3)	Lt. F. B. Schwenneker
CEBU (ARG-6)	Comdr. D. B. Candler
CREON (ARL-11)	Lt. Comdr. H. T. Smith
SPHINX (ARL-24)	Lt. (jg) H. G. Salisbury
FULTON (AS-11)	Capt. A. R. St. Angelo
SIOUX (ATF-75)	Lt. W. H. Moore
CHOWANOC (ATF-100)	Lt. Comdr. F. C. Ziesenhenne
LIMESTONE (IX-158)	Ens. J. H. Richter
ARD-29	Lt. J. B. Warner
ATA-124	Lt. (jg) F. H. La Pierre
ATA-187	Lt. E. B. Terrio
LST-388	Lt. (jg) P. H. Sullivan
LST-861	Lt. J. T. Gordon
YC-1009	

Ship	*Commanding Officer*
YF-385	
YF-733	
YF-734	
YF-735	
YF-752	
YF-753	
YF-754	
YF-990	
YF-991	
YF-992	
MUNSEE (ATF-107)	Lt. J. Buday
WENATCHEE (ATF-118)	Lt. T. P. Pierce
WILDCAT (AW-2)	Comdr. R. N. Newton
QUARTZ (IX-150)	Lt. (jg) R. K. Ritzett
YO-132	
YO-199	
YOG-63	
YOG-70	
YW-92	

(h) *Salvage Unit* (Task Unit 1.2.7, commanded by Captain B. E. Manseau (Navy))

PALMYRA (ARST-3)	Lt. Comdr. R. H. Drazell
PRESERVER (ARS-8)	Lt. C. B. Hiner
CURRENT (ARS-22)	Lt. H. F. Gindling
DELIVER (ARS-23)	Lt. F. F. Sharp
CLAMP (ARS-33)	Lt. Comdr. S. D. Frey
CONSERVER (ARS-39)	Lt. Comdr. C. H. Rooklidge
RECLAIMER (ARS-42)	Lt. J. S. Lees
CHICKASAW (ATF-83)	Lt. Comdr. F. H. Matthews
ACHOMAWI (ATF-148)	Lt. C. H. McCullar
WIDGEON (ASR-1)	Lt. A. F. Hamby
COUCAL (ASR-8)	Lt. J. E. Reid
GYPSY (ARSD-1)	Lt. Comdr. C. S. Horner
MENDER (ARSD-2)	Lt. Comdr. A. V. Swarthout
ETLAH (AN-79)	Lt. L. E. Marsh
SUNCOCK (AN-80)	Lt. L. G. Hickle
ONEOTA (AN-85)	Lt. (jg) J. B. Birtch
SKAKAMAXON (AN-86)	Lt. (jg) M. F. Root
ATA-180	Lt. E. R. Weaver
ATA-185	Lt. R. B. Leonnig
ATA-192	Lt. (jg) A. Morris
ATR-40	Lt. A. J. Roberts
ATR-87	Lt. R. E. Ward
LST-1184	
LCT-1420	

(i) *Despatch Boat and Boat Pool Unit* (Task Unit 1.8.3, commanded by Comdr. J. G. Blanche)

SAN MARCOS (LSD-25)	Comdr. J. G. Blanche
GUNSTON HALL (LSD-5)	Lt. Comdr. W. H. Barchmann

Ship	*Commanding Officer*
PRESQUE ISLE (APB-44)	Lt. B. F. Caver
PGM-23	Lt. (jg) E. A. Clark
PGM-24	Lt. (jg) J. W. Ferrill
PGM-25	Lt. (jg) J. T. Moss
PGM-29	Lt. (jg) N. C. Thomas
PGM-31	Lt. (jg) J. L. DeBlock
PGM-32	Lt. (jg) G. A. Oberle
LCI-977	Lt. (jg) H. P. Cohn
LCI-1062	Ens. H. W. Phipps
LCI-1067	Ens. E. R. Nutter
LCI-1091	Lt. L. F. Koch
LCT-1116	Lt. L. F. Koch
LCT-1130	Lt. (jg) J. D. Simmons
LCT-1132	
LCT-1155	
LCT-1268	
LCT-1341	
LCT-1361	Lt. (jg) P. M. Mitchell
LCT-1377	
LCT-1415	
LCT-1461	Ens. J. T. Jans

(j) *Medical Unit* (Task Unit 1.8.4, commanded by Captain E. P. Creehan (Navy))

BOUNTIFUL (AH-9)	Capt. D. M. Mackey
BENEVOLENCE (AH-13)	Capt. E. P. Creehan

(k) *Survey Unit* (Task Unit 1.8.5, commanded by Captain C. B. Schiano (Navy))

BOWDITCH (AGS-4)	Capt. C. B. Schiano
JOHN BLISH (AGS-10)	Lt. F. A. Wodke
JAMES M. GILLISS (AGS-13)	Lt. E. E. Simms
YP-636	Lt. C. D. Bailey
YMS-354	Ens. E. J. Litty
YMS-358	Ens. C. M. Clancy
YMS-413	Ens. V. P. Finos
YMS-463	Ens. R. H. Zisette

(l) *Evacuation Unit* (Task Unit 1.8.7, commanded by Lieutenant G. H. Gromer (Navy))

LST-871	Ens. M. B. Fletcher
LST-989	Lt. G. H. Gromer

Appendix 9

Target Vessels, Test A

(Note: all target vessels were under the general command of Rear Admiral F. G. Fahrion, commander of Task Group 1.2)

Ship	*Commanding Officer*
(a) *Battleships and Cruisers* (Task Unit 1.2.1, commanded by Captain W. Deweese)	
ARKANSAS, BB-33	Capt. W. Deweese
NEW YORK, BB-34	Capt. L. H. Bibby
NEVADA, BB-36	Capt. C. C. Adell
PENNSYLVANIA, BB-38	Capt. C. H. Bushnell
PENSACOLA, CA-24	Capt. D. J. Ramsey
SALT LAKE CITY, CA-25	Capt. J. Conner
NAGATO, Japanese BB	Capt. W. J. Whipple
SAKAWA, Japanese CL	Capt. H. L. Stone
PRINZ EUGEN, IX--300	Capt. A. H. Graubart
(b) *Aircraft Carriers* (Task Unit 1.2.2, commanded by Captain N. M. Kindell)	
SARATOGA, CV-3	Capt. O. S. MacMahan
INDEPENDENCE, CVL-22	Capt. N. M. Kindell
(c) *Destroyers* (Task Unit 1.2.3, commanded by Comdr. L. W. Sedgwick)	
LAMSON, DD-367	Lt. Comdr. H. H. Ellison
CONYNGHAM, DD-371	Lt. Comdr. F. W. Bampton
MUGFORD, DD-389	Comdr. M. Harvey
TALBOT, DD-390	Lt. Comdr. B. W. Spore
MAYRANT, DD-402	Comdr. M. H. Buaas
RHIND, DD-404	Lt. Comdr. D. M. Sharer
STACK, DD-406	Comdr. E. A. Shuman
WILSON, DD-408	Lt. Comdr. R. H. Pauli
HUGHES, DD-410	Comdr. D. S. Bill, Jr.
ANDERSON, DD-411	Lt. Comdr. J. J. McMullen
MUSTIN, DD-413	Lt. Comdr. J. C. Mathews
WAINWRIGHT, DD-419	Comdr. L. W. Sedgwick
(d) *Submarines* (Task Unit 1.2.4, commanded by Comdr. R. A. Waugh)	
SKIPJACK, SS-184	Lt. Comdr. F. J. Coulter
SEARAVEN, SS-196	Lt. Comdr. R. C. Smallwood, Jr.
TUNA, SS-203	Lt. Comdr. G. Jacobsen
SKATE, SS-305	Lt. Comdr. E. P. Huey
APOGON, SS-308	Lt. Comdr. J. W. Johnson

Ship	*Commanding Officer*
DENTUDA, SS-335	Comdr. R. A. Waugh
PARCHE, SS-384	Lt. Comdr. H. G. Reaves
PILOTFISH, SS-386	Lt. Comdr. R. B. Laning

(e) *Landing Craft* (Task Unit 1.2.5)

LST 52	Lt. (jg) C. E. Boggs
LST 220	Lt. (jg) J. O. Marzluff
LST 545	Lt. (jg) S. L. Voiler
LST 661	Lt. W. F. Marlow
LCI 327	Ens. R. P. Lemke
LCI 329	Ens. R. C. Hayes
LCI 332	Ens. W. F. Zartman
LCI 549	Lt. (jg) W. F. Fergusen
LCT 745	
LCT 816	
LCT 818	
LCT 874	
LCT 1013	
LCT 1078	
LCT 1112	
LCT 1113	
LCM 1	

(f) *Merchant-Type Ships* (Task Unit 1.2.6, commanded by Capt. W. H. Standley, Jr.)

GILLIAM, APA-57	Capt. D. F. Williamson
BANNER, APA-60	Comdr. W. L. Kitch
BARROW, APA-61	Comdr. J. E. Kendall
BLADEN, APA-63	Capt. L. S. Mewhinney
BRACKEN, APA-64	Comdr. C. S. Lee
BRISCOE, APA-65	Capt. W. S. Rodimon
BRULE, APA-66	Lt. Comdr. A. B. Taylor
BUTTE, APA-68	Capt. A. R. Montgomery
CARLISLE, APA-69	Comdr. E. T. Goyette
CARTERET, APA, 70	Lt. Com. J. L. Hunter
CATRON, APA-71	Capt. E. B. Ellis
CORTLAND, APA-75	Comdr. J. L. Haines
CRITTENDEN, APA, 77	Capt. P. C. Crosley
DAWSON, APA-79	Capt. D. D. Humphreys
FALLON, APA-81	Comdr. W. W. Sackett
FILMORE, APA-83	Capt. L. E. Divoll
GASCONADE, APA-85	Capt. A. S. Carter
GENEVA, APA-86	Capt. P. J. Neimo
NIAGARA, AP-87	Capt. W. H. Standley, Jr.

(g) *Concrete Drydocks and Barges*

YO-160
YOG-83
ARDC-13

Appendix 10

Preliminary Statement by the Evaluation Board on Test A

The following preliminary statement on Test A was prepared by the Joint Chiefs of Staff's Evaluation Board immediately following Test A. The statement was released by the White House on July 11, 1946.

* * * *

The members of the Board inspected target ships the day before the test, witnessed the explosion from an airplane twenty miles distant, and then approached to within nine miles for a brief view. On the following day, as soon as safety clearance had been received, the members flew to Bikini and began their examination of ship damage. Many photographs had been studied, and military and scientific specialists interviewed in an attempt to obtain an over-all understanding of test results prior to the compilation of all the data.

From its previous study of the plans for the test, and from its observations in the Bikini Area, the Board considers that the test was well conceived and well executed by the services in close cooperation with a large civilian staff. It is satisfied in that the conditions of the test were well-chosen and that the highest skill and ingenuity have been used to obtain a maximum amount of data in an unbiased, scientific manner. It believes that the commander, staff, and personnel of Task Force One deserve high commendation for their excellent performance and their notable cooperative spirit.

Effective precautions appear to have been taken to safeguard personnel against radioactivity and associated dangers.

The Board's present information is that the bomb exploded with an intensity which approached the best of the three previous bombs, over a point 1500 to 2000 feet westerly of the assigned target, and at approximately the planned altitude.

The target array in no sense represented an actual naval disposition but was designed to obtain the maximum data from a single explosion. The most important effects produced by the bomb are the following:

a. A destroyer and two transports sank promptly and another destroyer capsized. It later sank, and the Japanese cruiser

SAKAWA sank the following day. The superstructure of the submarine SKATE was so badly damaged as to make it unsafe to submerge the vessel. The light carrier INDEPENDENCE was badly wrecked by the explosion, gutted by fire, and further damaged by internal explosions of low order, including those of torpedoes. All the above vessels were within one-half mile of the explosion point.

b. Numerous fires were started on other ships, including one on a ship two miles distant, which was apparently due to some unusual circumstance since the other fires were much closer. Here it should be remembered that the target ship decks carried a great variety of test material not ordinarily exposed on the decks of naval vessels.

c. The only major combatant ships within one-half mile of the explosion point were the battleships NEVADA and ARKANSAS and the heavy cruiser PENSACOLA. The blast struck these from the after quarter. Apparently little damage was done to their hulls or their main turrets but their superstructures were badly wrecked. These ships were unquestionably put out of action and would, along with many others within three-fourths of a mile, have required extensive repairs at a principal naval base.

d. Other ships on the target array suffered damage in varying degree, depending on position and type of ship, but there was relatively little damage at distances greater than three-fourths of a mile.

e. The primary material effects noted were due to blast, buckling of decks and bulkheads, and destruction or deformation of lightly constructed exposed objects, including stacks, masts, and antennae. Secondary effects were due to fire, and it is noteworthy that Army Quartermaster stores and miscellaneous equipment placed on the decks for the test proved more vulnerable than normal naval deck gear. It should be pointed out that since the targets carried no personnel the fires were uncontrolled and undoubtedly there was more damage than there would have been under battle conditions. Singularly, although considerable amounts of explosive ordnance were exposed on decks and in gun turrets, there is no indication on ships which remained afloat that any of this material was exploded by direct action of the atomic bomb. Fire-fighting ships entered the target area as soon as they could obtain radiological security permission and subdued a number of fires. The speed and efficiency with which these ships acted preserved for later examination a great deal of evidence of bomb action which might otherwise have been lost.

f. Examination of the flashburn effects produced by the initial radiation from the explosion indicates that casualties would have been high among exposed personnel. However, it is the opinion of the Board that persons sheltered within the hull of a ship or even on deck in the shadow of radiation from the bomb would not have been immediately incapacitated by burns alone, whatever have been the subsequent radiological effects.

g. Within the area of extensive blast damage to ship superstructures there is evidence that personnel within the ships would have been exposed to a lethal dosage of radiological effects.

Personnel casualties due to blast would no doubt have been high for those in exposed positions on vessels within one-half mile of the target center. Beyond this, any discussion of the blast effect upon personnel will have to await the detailed reports of the medical specialists.

In general no significant unexpected phenomena occurred, although the test was designed to cope with considerable variation from predictions. There was no large water wave formed. The radioactive residue dissipated in the manner expected. No damage occurred on Bikini Island, about three miles from the explosion center.

From what it has seen and from what it has ascertained from data now available, the Board is able to make certain general observations:

a. The atomic bomb dropped at Bikini damaged more ships than have ever before been damaged by a single explosion.

b. The test has provided adequate data of a sort necessary for the redesign of naval vessels to minimize damage to superstructures and deck personnel from this type of bomb. Because of the nature of the first test (air blast) little information has been obtained on hull effects. Damage to ships' hulls will be studied specifically in the second test when a bomb will be exploded under water.

c. A vast amount of data which will prove invaluable throughout scientific and engineering fields has been made available by this test. Once more the importance of large-scale research has been dramatically demonstrated. There can be no question that the effort and expense involved in this test has been amply justified both by the information secured and by greatly narrowing the range of speculation and argument. Moreover, it is clear to the Board that only by further large-scale research and development can the United States retain its present position of scientific leadership. This must be done in the interests of national safety.

The board desires to say that it has had the fullest cooperation of the task force commander, and that every opportunity has been afforded it in carrying out its mission. The members of the Board have had access to all data thus far accumulated and have had every facility for personally inspecting the results of the test.

Appendix 11

Preliminary Statement by the Evaluation Board on Test B

The following preliminary statement on Test B was prepared by the Joint Chiefs of Staff's Evaluation Board immediately following Test B. The statement was released by the White House on August 2, 1946.

* * * *

SECTION I

Supplement to Preliminary Report on Test "A"

In general, the observations on ship damage presented by this board in its first report were confirmed by engineering surveys. The location of the bomb burst, accurately determined from photographs, was such that only one ship was within 1,000 feet of the surface point over which the bomb exploded. There were about 20 ships within half a mile, all of which were badly damaged, many being put out of action and five sunk. It required up to 12 days to repair all of those ships left afloat sufficiently so that they could have steamed under their own power to a major base for repair.

It is now possible to make some estimate of the radiological injuries which crews would have suffered had they been aboard Test "A" target vessels. Measurements of radiation intensity and a study of animals exposed in ships show that the initial flash of principal lethal radiations, which are gamma-rays and neutrons, would have killed almost all personnel normally stationed aboard the ships centered around the air burst and many others at greater distances. Personnel protected by steel, water, or other dense materials would have been relatively safe in the outlying target vessels. The effects of radiation exposure would not have incapacitated all victims immediately, even some of the most severely affected might have remained at their stations several hours. Thus it is possible that initial efforts at damage control might have kept ships operating, but it is clear that vessels within a mile of an atomic bomb air burst would eventually become inoperative due to crew casualties.

SECTION II

Observations on Test "B"

The Board divided into two groups for the observation of Test "B." Four members, after surveying the target array from the air, witnessed the explosion from an airplane eight miles away at an altitude of 7,500 feet. The other three members inspected the target array from a small boat the day before the test and observed the bomb's explosion from the deck of the USS HAVEN, 11 miles at sea to the east of the burst.

The Board reassembled on the HAVEN on July 26, and the members have since examined photographs, data on radioactivity, and reports of other phenomena, and have inspected some of the target vessels. They have also consulted with members of the Task Force technical staff.

As scheduled, at 0835 Bikini time on July 25, a bomb was detonated well below the surface of the lagoon. This bomb was suspended from LSM-60, near the center of the target array. The explosion was of predicted violence, and is estimated to have been at least as destructive as 20,000 tons of TNT.

To a degree which the Board finds remarkable, the visible phenomena of explosion followed the predictions made by civilian and service phenomenologists attached to Joint Task Force One. At the moment of the explosion, a dome, which showed the light of incandescent material within, rose upon the surface of the lagoon. The blast was followed by an opaque cloud which rapidly enveloped about half of the target array. The cloud vanished in about two seconds to reveal, as predicted, a column of ascending water. From some of the photographs it appears that this column lifted the 26,000-ton battleship ARKANSAS for a brief interval before the vessel plunged to the bottom of the lagoon. Confirmation of this occurrence must await the analysis of high-speed photographs which are not yet available.

The diameter of the column of water was about 2,200 feet, and it rose to a height of about 5,500 feet. Spray rose to a much greater height. The column contained roughly ten million tons of water. For several minutes after the column reached maximum height, water fell back, forming an expanding cloud of spray which engulfed about half of the target array. Surrounding the base of the column was a wall of foaming water several hundred feet high.

Waves outside the water column, about 1,000 feet from the center of explosion, were 80 to 100 feet in height. These waves rapidly diminished in size as they proceeded outward, the highest wave reaching the beach of Bikini Island being seven feet. Waves did not pass over the island, and no material damage occurred there. Measurements of the underwater shock wave are not yet available. There were no seismic phenomena of significant magnitude.

The explosion produced intense radioactivity in the waters of the lagoon. Radioactivity immediately after the burst is estimated to have been the equivalent of many hundred tons of radium. A few minutes exposure to this intense radiation at its peak would, within a brief interval, have incapacitated human beings and have resulted in their death within days or weeks.

Great quantities of radioactive water descended upon the ships from the column or were thrown over them by waves. This highly lethal radioactive water constituted such a hazard that after four days it was still unsafe for inspection parties, operating within a well-established safety margin, to spend any useful length of time at the center of the target area or to board ships anchored there.

As in Test "A," the array of target ships for Test "B" did not represent a normal anchorage but was designed instead to obtain the maximum data from a single explosion. Of the 84 ships and small craft in the array, 40 were anchored within one mile and 20 within about one-half mile. Two major ships were sunk, the battleship ARKANSAS immediately and the heavy-hulled aircraft carrier SARATOGA after 7½ hours. A landing ship, a landing craft, and an oiler also sank immediately. The destroyer HUGHES, in sinking condition, and the transport FALCON, badly listing, were later beached. The submerged submarine APOGON was sent to the bottom emitting air bubbles and fuel oil, and one to three other submerged submarines are believed to have sunk. Five days after the burst, the badly damaged Japanese battleship NAGATO sank. It was found impossible immediately to assess damage to hulls, power plants and machinery of the target ships because of radioactive contamination. Full appraisal of damage will have to await detailed survey by engineer teams. External observation from a safe distance would indicate that a few additional ships near the target center may have suffered some hull damage. There was no obvious damage to ships more than one-half mile from the burst.

SECTION III

Observations and Conclusions, Both Tests

The operations of Joint Task Force One in conducting the tests have set a pattern for close, effective cooperation of the Armed Services and civilian scientists in the planning and execution of this highly technical operation. Moreover, the tests have provided valuable training of personnel in joint operations requiring great precision and coordination of effort.

It is impossible to evaluate an atomic burst in terms of conventional explosives. As to detonation and blast effects, where the largest bomb of the past was effective within a radius of a few hundred feet, the atomic bomb's effectiveness can be measured in thousands of feet. However, the radiological effects have no parallel in conventional weapons. It is necessary that a conventional bomb score a direct hit or a near miss of not more than a few feet to cause significant damage to a battleship. At Bikini the second bomb, bursting under water, sank a battleship immediately at a distance of well over 500 feet. It damaged an aircraft carrier so that it sank in a few hours, while another battleship sank after five days. The first bomb, bursting in air, did great harm to the superstructures of major ships within a half-mile radius, but did only minor damage to their hulls. No ship within a mile of either burst could have escaped without some damage to itself and serious injury to a large number of its crew.

Although lethal results might have been more or less equivalent, the radiological phenomena accompanying the two bursts were markedly different. In the case of the air-burst bomb, it seems certain that unprotected personnel within one mile would have suffered high casualties by intense neutron and gamma radiation as well as by blast and heat. Those surviving immediate effects would not have been menaced by radioactivity persisting after the burst.

In the case of the underwater explosion, the air-burst wave was far less intense and there was no heat wave of significance. Moreover, because of the absorption of neutrons and gamma rays by water, the lethal quality of the first flash of radiation was not of high order. But the second bomb threw large masses of highly radioactive water onto the decks and into the hulls of vessels. These contaminated ships became radioactive stoves, and would have burned all living things aboard them with invisible and painless but deadly radiation.

It is too soon to attempt an analysis of all of the implications of the Bikini tests. But it is not too soon to point to the necessity for immediate and intensive research into several unique problems posed by the atomic bomb. The poisoning of large volumes of water presents such a problem. Study must be given to procedures for protecting not only ships' crews but also the populations of cities against such radiological effects as were demonstrated in Bikini lagoon.

Observations during the two tests have established the general types and range of effectiveness of air and shallow underwater atomic-bomb bursts on naval vessels, army materiel, including a wide variety of Quartermaster stores, and personnel. From these observations and from instrumental data it will now be possible to outline such changes, not only in military and naval design but also in strategy and tactics, as future events may indicate.

National security dictates the adoption of a policy of instant readiness to defend ourselves vigorously against any threat of atomic weapon attack at any time and adherence to this policy until it is certain that there can never be an atomic war. One enduring principle of war has not been altered by the advent of the atomic weapon. Offensive strength will remain the best defense. Therefore, so long as atomic bombs could conceivably be used against this country, the Board urges the continued production of atomic material and research and development in all fields related to atomic warfare.

Appendix 12

Preliminary Statement by the Evaluation Commission on Test A

The following preliminary statement on Test A was prepared by the President's Evaluation Commission immediately following Test A. The statement was released by the White House on July 11, 1946.

* * * *

Dear Mr. President:

Your Evaluation Commission, divided between positions at sea and in the air, witnessed the First Bikini Test, at 33 seconds after 9:00 A.M., local time on July 1st, and has since completed a survey of the damage. The Second Test, wherein the bomb will be exploded under water, will in some respects be of even greater interest, for it will have no precedent.

The report of your Commission required by its directives of May 18th must await the assembling of considerable data deriving from instrumental and photographic measurements and analysis of fission product samples. However, we believe that it lies within the scope of your directive and may be of possible assistance to you, to submit, now, the following brief observations made from the layman's point of view, but with such accuracy as is presently available:

1. The organization and execution of the operation was magnificently handled and has commanded our continuous admiration. The bomb was dropped under favorable weather conditions about 30 seconds after the time set. The greatest credit is due Admiral Blandy and the officers and enlisted personnel of both services who, with scientists and other civilians, have served and are serving under him with a display of team work that must be seen to be fully appreciated.

2. Their conservatively safe distance from the burst led many observers to entertain an initial opinion that the bomb employed was somewhat under par. It is now, however, safe to state that the energy was of the same order of magnitude as in the case of previous atomic detonations, between the highest and lowest of this bomb's three predecessors.

3. The accuracy of the drop was such that the explosion occurred within the area included within the allowance for the probable error of the elevation of drop, and detonation was probably within 100 feet of the chosen altitude. Nevertheless, the explosion actually occurred several hundred yards west of a point directly above the target ship NEVADA and therefore entirely west of the closely spaced array of capital ships.

4. There were 90 targets anchored in the lagoon when the bomb exploded. These were not in battle formation but were placed in positions to give the largest amount of desired technical information with especially close concentration around the center target point. Those ships anchored a mile or more from the point of drop largely escaped injury. Those within a mile were sunk or suffered damage varying with the distance from the point of detonation and with the type of ship construction. On explosion, a destroyer and two transports sank promptly. A second destroyer and the Japanese cruiser SAKAWA sank within twenty-seven hours. The light carrier INDEPENDENCE was gutted with fire and resultant explosions. The submarine SKATE was heavily damaged and later towed away. All of these were near the point of explosion. The other ships, including the only two capital ships which were within one-half mile of the detonation, received damage that would require more or less complete overhaul and in most cases repair at major bases before they could again be used in combat. A study of this damage will point the way to changes in design which should minimize damage from blast and heat. Beyond these ships there was extensive damage to superstructure, radar, and fire control. Had the ships within the damage area been manned, casualties and psychological injuries would have required a large percentage of replacements. Until the readings of complex instruments and the future life history of animals within the ships have been determined no accurate appraisal of potential damage to humans within the ships can be made.

5. No wave or blast damage could be noticed on Bikini Island, which is approximately three miles from the point of detonation.

6. We are of the unanimous opinion that the first test amply justified the expenditure required to conduct it and that the second test is equally desirable and necessary. You made a wise decision when you approved the plans for these tests and they have been carried out with extraordinary skill, diligence and ingenuity. The test just completed has again proven that the atomic bomb is a weapon of terrific power when used on land or sea.

Appendix 13

Preliminary Statement by the Evaluation Commissionon on Test B

The following preliminary statement on Test B was prepared by the President's Evaluation Commission immediately following Test B. The statement was released by the White House on August 2, 1946.

* * * *

Dear Mr. President:

Your acknowledgment on July 7th of our preliminary report on the first test at Bikini was much appreciated.

The second test was conducted in the same area, July 25, local time, and on the same target ships less those sunk in the first test. The bomb was exploded under a moderate depth of water at 8:30, a.m., local time, on schedule. Weather conditions were perfect. Seven members of your committee witnessed the results from the USS HAVEN stationed 11 miles from the point where the bomb exploded. There was no requirement of dark glasses for this test, and the target ships were readily visible to the naked eye and easily distinguishable with the aid of binoculars.

Our previous report endeavored to express our appreciation of the cooperation, assistance and unfailing courtesy extended by Admiral Blandy and by the officers and enlisted men and civilian scientific personnel of Joint Task Force One. Throughout, this attitude of interest and diligence has remained at the same high level, and the effect of longer observation of operations and better acquaintance with officers and men has been to convince us that you and the people of the United States can place the utmost reliance on the fairness, thoroughness and real effort for the maximum of honest information which has characterized these tests. This disposition has expedited and lightened our task in complying with your directive. These tests have consistently adhered to the stated purpose of the mission: "Primarily to determine the effects of the atomic bomb on naval vessels in order to gain information of value to the national defense."

In the interval between tests the target ships were redeployed in respect to the point chosen for the second explosion so as to furnish maximum scientific and technical information from expected results.

When the bomb exploded, the battleship ARKANSAS, nearest to the center of impact, and three other smaller ships sank at once. The aircraft carrier SARATOGA, also placed close by, sank 7½ hours later. As soon as radioactivity lessened sufficiently to permit safe operations, the destroyer HUGHES and the attack transport FALLON were beached to prevent their possible sinking. Of the eight submarines involved, six were submerged. Several of these appear to be injured and one at least has gone to the bottom. The two on the surface are not noticeably injured. All but a few of the target ships were drenched with radioactive sea water, and all within the zone of evident damage are still unsafe to board. It is estimated that the radioactivity dispersed in the water was the equivalent to that from many hundred tons of radium.

We believe that interesting distinctions between the general results of the two explosions can even now be drawn without the risk of serious error. Both explosions sank several ships. From the limited observations we have thus far been able to make, the ships remaining afloat within the damage area appear to have been more seriously damaged by the aerial explosion than by the submarine explosion. The damage to ships in the first test might have been far greater if the bomb had exploded directly over the target ship, the NEVADA.

In the first test much of the personnel within the ships would have received fatal doses of neutrons and gamma rays from the first deadly flash. On the other hand, the deadly effects of persistent radioactivity would have been much more severe in the second test. Had the target array been manned, it seems clear that casualties and both physical and psychological injury to personnel would have been very great. Rescue and attention to casualties would be difficult and dangerous. Within 2000 yards of explosion, ships would probably have been inoperative and a lapse of weeks might well ensue before relatively undamaged ships could again be used in combat.

The second bomb caused a deluge of water loaded with deadly radioactive elements over an area that embraced 90 per cent of the target array. Such results might be as disastrous to the fleet as results of the first test, although in part for different reasons. An enemy possessed of two or more bombs might well so dispose them as to create simultaneously the deadly features of both tests. Such tactics might effectively dispose of a fleet for many months; for example, consider a Pearl Harbor attack on these lines.

The results of both tests are already under study by the Bureau of Ships and will undoubtedly point the way to changes in ships' size, design and structure, both above and below the water line. Such changes can offer increased immunity to flash and blast effect. but protection from catastrophe by deadly gamma and neutron radiations lies rather in wide spacing of task forces and decentralization of navy yards, repair and loading facilities, of ships within ports, and amongst all available harbors. We are convinced distance is the best defense.

As was demonstrated by the terrible havoc wrought at Hiroshima and Nagasaki, the Bikini tests strongly indicate that future wars employing atomic bombs may well destroy nations and change present standards of civilization. To us who have witnessed the devastating effects of these tests, it is evident that if there is to be any security or safety in the world, war must be eliminated as a means of settling differences among nations.

Appendix 14

Test C (Cancelled)

Prior to its cancellation by the President, the proposed "Test C" was the center of much discussion. In this test an atomic bomb was to be exploded at great depth beneath the surface of the water.

Persons favoring holding such a test believed that it would produce an underwater shockwave of almost incredible violence. Ships might be crushed at ranges not equaled by explosions in air or by shallow-underwater explosions. Involving an entirely new kind of explosion, the test might fill a large gap in physicists' understanding of explosion phenomena. Would a great "gas bubble," hundreds of yards in diameter, break through the surface? Or would the surface remain unbroken? Would great waves be produced? Some cynics, believing that this type of test would produce the most damage, thought the Navy would try to avoid it.

To many persons it was clear that this test would be less important than the other two. On the technical side it was obvious that little or no thermal radiation would reach the surface. Neutron and gamma radiations also would be almost completely muffled by the intervening layer of water. The tactical considerations were even more pertinent. Nearly all harbors are shallow; most coastal waters are shallow. Thus a deep underwater explosion could never be used in these important regions. It would be applicable only in the open ocean, and here, of course, a fleet could be dispersed as widely as necessary so that only one or two ships could be sunk by one atomic bomb.

Nevertheless, plans were made to hold Test C, and a considerable amount of preparatory work was done. Studies were made as to how to position the target ships accurately. Anchoring being impractical in very deep water, thought was given to "streaming" the ships. They could be fastened to a small island by means of long cables, and then allowed to take up more or less fixed positions determined by the direction of the ocean currents and by the lengths of the cables. Or perhaps the ships could be powered and underway, steered by radio. Work was started also on methods of lowering the bomb to the desired depth, holding it in the desired position despite the ocean currents, and firing it. It was expected that the test would be held near Bikini Atoll, and construction crews went to work preparing necessary installations there.

But the success of the first two tests, together with the increasing shortage of military personnel and available civilian scientists, caused reconsideration of the desirability of holding this third test. And on September 7, 1946, President Truman, acting with the advice of the Joint Chiefs of Staff, postponed the test indefinitely. His statement was as follows:

> "In view of the successful completion of the first two atomic bomb tests of Operation Crossroads and the information derived therefrom, the Joint Chiefs of Staff have concluded that the third explosion, Test C, should not be conducted in the near future. . . .
>
> "The additional information of value expected to result from Test C is such that the Joint Chiefs of Staff do not feel that completion of the test in the near future is justified."

Appendix 15

Chronology of Atomic Bomb Detonations

Five atomic bombs have been detonated to date. The times and places of their detonation are as follows:

Bomb No.	*Place*	*Time*
1	Alamogordo, N. M.	MWT: July 16, 1945, at 5:30 a.m. EWT: July 16, 1945, at 7:30 a.m. GCT: July 16, 1945, at 11:30 a.m.
2	Hiroshima, Japan	Local Time: Aug. 6, 1945, at 8:15 a.m. EWT: Aug. 5, 1945, at 7:15 p.m. GCT: Aug. 5, 1945, at 11:15 p.m.
3	Nagasaki, Japan	Local Time: Aug. 9, 1945, at 10:58 a.m. EWT: Aug. 8, 1945, at 9:58 p.m. GCT: Aug. 9, 1945, at 1:58 a.m.
4	Bikini (in air)	Local Time: July 1, 1946, at 34 seconds after 9:00 a.m. EST: June 30, 1946, at 34 seconds after 5:00 p.m. GCT: June 30, 1946, at 34 seconds after 10:00 p.m.
5	Bikini (underwater)	Local Time: July 25, 1946, at 59.7 seconds after 8:34 a.m. EST: July 24, 1946, at 59.7 seconds after 4.34 p.m. GCT: July 24, 1946, at 59.7 seconds after 9:34 p.m.

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