CHAPTER XXXVII

The Role of Radiology in the Development of the Atomic Bomb

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THE BACKGROUND OF THE ATOMIC BOMB

This chapter of the history of radiology in World War II tells the story, in necessarily brief form, of the role of radiology in the development of the atomic bomb that was first detonated at Alamogordo, N. Mex., on 16 July 1945, dropped for military purposes on Hiroshima, Japan, on 6 August 1945, and at Nagasaki 3 days later.

The atomic bomb had been in the making indirectly for at least 15 years and directly for the preceding 3 years. Since it was an entirely new development, a certain amount of background information is necessary to make clear the relation between its military aspects and its medical aspects, which were practically entirely radiologic. Therapy did not enter the picture in the Zone of Interior because there were no radiation casualties.

Even when it was militarily over Japan in August 1945, each bomb was still a scientific device, an experimental model, and the first of its kind. Before these bombs could be dropped, a new agency had to be created, the Manhattan District of the Corps of Engineers. The uranium oxide required for the manufacture of the bombs came from several sources, about a seventh of it from the network of mines in Colorado that had been actively developed early in the war to supply the large demand for vanadium in war industry. The uranium oxide for the Manhattan Project came not from further mining operations but from refining the large stockpiles of vanadium tailings at these mines. Ores were imported also from Canada and the Congo. Ore-refining and metallurgical plants were set up all over the United States. Finally, new techniques had to be developed for the fabrication and delivery of uranium 238, the metal used in making material for atomic bombs.

Many other scarce materials were required for the production process and the chain-reacting piles. The procurement of these materials would have been impossible without the high priorities assigned by the War Department for all the operations of the MED (Manhattan Engineer District).

Probably close to a million civilians were engaged, directly or indirectly, in this gigantic effort during the final 6 months of the war.

There were three so-called secret cities (sites) involved in the production of the bomb and the materials for it:

1. Oak Ridge, Tenn., which in 1945 had a resident population of more than 70,000. It was responsible for the isotopic separation of U-235 from U-238, which could be accomplished readily by three different methods (p. 854).

2. Hanford and Richland, Wash., on the Columbia River. Here, plutonium Pu-239), another bomb material, was manufactured from U-238 in chain-reacting piles.

3. Los Alamos, N. Mex., situated on the top of an almost inaccessible mesa. Here was located the scientific-engineering laboratory for both the design and the fabrication of the bombs.

The first bomb was tested on 16 July 1945, on a high tower—which disintegrated during the detonation—at Alamogordo (p. 884). This site was part of an Air Force bombing range in the desert—Jornada del Muerto—south of Carthage.

Among the university and federal laboratories engaged in extensive secret isotope separation projects were:

1. The Columbia University Laboratory, N.Y. (under Harold C. Urey, Ph. D.), known as the SAM (Special Alloyed Materials) Laboratory.

2. The University of California Radiation Laboratories (under Ernest O. Lawrence, Ph. D.).

3. The Special Research Division, the Naval Research Laboratory (under Philip H. Abelson, Ph. D.).

4. The National Bureau of Standards (under Lyman J. Briggs, Ph. D.).

5. The University of Chicago Metallurgical Laboratory, generally known as the Met Lab (under Arthur H. Compton, Ph. D.).

Manufacturing plants that participated in the project were numbered in the hundreds and were distributed all over the country.

Every step of these research and manufacturing processes in which uranium or plutonium was used was fraught with radiation hazards. Some of these hazards were—or could have been—of fantastic magnitude, such as those from the pile ashes produced during the chemical extraction of plutonium from neutron-bombarded U-238. Every step in the procurement of U-238 from mining to metal fabrication was accompanied by the constant production of the unwanted and dangerous daughter-products, uranium X1 and uranium X2, which are strong beta-radiation emitters.

Radiologists had had a wide experience with high voltage X-rays and with radium or radon, as well as a more limited recent experience with radioactive isotopes. They were familiar with tissue reactions from radiation and with the lethal effects and absorption dangers from X-rays, gamma and beta rays, alpha particles, and neutrons. They also possessed electroscopes, roentgen meters, and ion chambers, all new and all at once in great demand. It was natural, therefore, that radiologists should constitute the initial personnel concerned with the protection of the workers in this vast organization.

RADIATION THERAPY

The principal approach of radiology to the atomic bomb was by way of the effects of radiation therapy, supplemented by the first laboratory experiments with radioactive isotopes. In the interim between the World Wars, radiation therapy was an empirical specialty rather than one based on precise fundamental knowledge. Its motivation was a frantic search, against hopeless odds, for a cure for cancer. The clinical diagnosis of cancer was still discouragingly inexact, and all too often the radiologist first saw the patient when his disease was already far advanced and already in the metastatic stage. Treatment therefore was usually little more than a temporizing procedure, intended only to relieve pain and reduce the bulk of the growth.

Although the radiotherapist was generally limited in both approach and facilities, some progress had been made before 1940 by courageous and imaginative workers in tracer technology (p. 835) and allied fields, who took advantage of the availability of radioactive isotopes in large quantities. Perhaps the first large-scale, well-organized therapeutic assault on malignant disease was on chronic leukemia and polycythemia by Dr. John H. Lawrence, at the University of California School of Medicine on the San Francisco campus, who used phosphorus 32 secured from the cyclotron developed by his brother, Dr. E. O. Lawrence, on the Berkeley Campus (*1, 2*). Dr. J. H. Lawrence's work was shortly verified at the Harvard University Medical School, Boston, Mass., by Dr. Shields Warren, who used similar material supplied by the Massachusetts Institute of Technology, Cambridge (*3*). In spite of the hopeful results obtained by both Dr. J. H. Lawrence and Dr. Shields Warren, clinical hematologists remained skeptical, and the controversy raged for years before the usefulness of radioactive isotopes in malignant disease was generally accepted.

STATUS OF PREWAR RADIOLOGIC RESEARCH

Research in radiology in the medical schools of the United States in the late 1930's was granted to be of some—though limited—value. It developed teachers. It provided a field of work for graduate students. It helped to train hospital residents, and there was considerable discussion about making some research work a minor requirement for certification in radiology. But research in radiology had little official recognition in the allocation of funds or the provision of space and facilities for it. Few research groups were adequately financed, efficiently organized, and properly equipped for basic experimental work in this field. Grants were small and were seldom given for more than a year. The investigator frequently had to build his own equipment, operate it in a basement or in some unfinished space in hospital or school, and use hospital radiation sources at night or on weekends. A machinist or a physicist was seldom available for more than part time, if that, and a grant that provided for a technician or two was a major production.

The system described was not productive of scholars or of significant research results. By its very nature it restricted research to small Arbeits that could be finished within a limited period of time (seldom more than a year) and that involved small numbers of small animals.

The results of this kind of research were seldom accepted until they had been repeated and verified by other observers, a criterion that often took several years. There was every reason why they should not be accepted offhand. The experiments were seldom well controlled. Not enough animals were used to be statistically significant. The variations normally present in small series of stock animals, particularly animals obtained from pounds, also altered results. Paucity of personnel and equipment and lack of continuity prevented any long-term studies of healing or degeneration after irradiation, though the need for specific information on these phenomena was apparent almost daily in cancer clinics. Growth and fertility cycles of larger animals were too long to fit into such an erratic pattern, and acute, short-term experiments had to be devised. The number of fruitful investigations of this type was limited, and many potential research workers lost interest.

The situation just described is not an exaggeration. It was characteristic of research and advanced training in radiology up to the outbreak of World War II. It was not until 1942, when data were urgently needed in the development of the atomic bomb, that funds for research and engineering became available in larger and significant amounts.

The cyclotron was first developed at the University of California in Berkeley in 1930 by Dr. E. O. Lawrence and his associates, and, as would be expected, some of the most active prewar experimentation and training were conducted there. The physiologic significance of these developments and of the associated development of instruments and techniques was soon recognized elsewhere, and active work along these lines began to be conducted in other universities. The clinical use of phosphorus 32 at the University of California by Dr. J. H. Lawrence has already been mentioned. In the Department of Radiology at the same school, Dr. Robert S. Stone and his group undertook therapeutic trials of high energy particles (neutrons from the Sloan generator) in cancer.

On both the Berkeley and the San Francisco campuses of the University of California young graduate students and young physicians were trained in these new techniques. By this fortunate circumstance, some of the men who played an outstanding role in the development of the atomic bomb were ready for assignment when the need arose to safeguard the health of the increasing numbers of participants in the University of Chicago Metallurgical Laboratory and the secret sites in which materials for the bomb were developed. Many well-trained young physicians were also produced at the University of Rochester, Rochester, N.Y. (p. 845), and later at the University of Chicago.

TRACER STUDIES

The advent of radioactive isotopes in the early 1930's promptly corrected the discouraging research situation just described and opened the way for an almost unlimited number of short, cheap, highly productive experiments that could be completed within a budget year. As a result, the end of this decade and the beginning of the 1940's saw a recrudescence of interest in radiation experiments, at a most propitious time for the development of the atomic bomb. The era of intensive study of dynamic metabolic and physiologic activity was now indeed at hand.

Tracer studies with stable isotopes were expensive, and most investigators also found them too difficult to be practical. These isotopes were therefore not widely used until after the war. Unstable radioactive isotopes, however, had many convenient attributes. Phosphorus 32, for instance, which was usually used as sodium phosphate, could be readily produced in the cyclotron by direct bombardment of the element, and no subsequent chemical steps were necessary to remove the stable phosphorus carrier; this step was necessary in many other radioactive isotopes. Phosphorus 32 was nontoxic and highly soluble. Its beta radiation was easily measured by available Geiger counters. It could be safely handled and easily shipped by mail, since its beta radioactivity was weak enough to be protected against by a standard laboratory brown bottle. When it was given intravenously or parenterally, it diffused widely in the body fluids and was readily excreted. Its relatively short half-life (14 days) and its high rate of excretion were attractive features in metabolic and physiologic experiments as well as in its clinical applications.

Because of its high chemical activity and its widespread presence in most body constituents, the use of P–32 as a radioactive tracer opened exciting pathways for study in almost every field of biology and medicine. The conventional chemistry of phosphorus and its salts is so complex that up to this time relatively little had been learned concerning its function in energy exchange. Now for the first time there was open to relatively easy investigation its role in the appetite minerals of bones and teeth, in which it participates in the binding of calcium, lead, radium, strontium and other metals, as well as its role in brain tissues and in the tissues of many other organs.

When isotopes once became available and their importance was recognized, there was almost as much interest in the application of tracer techniques as there was in the development of the atom itself. In fact, supplying radioactive isotopes for biologic investigation consumed so much time in the laboratories that owned cyclotrons that it often interfered with the experimental work underway in physics.

The first work with cyclotrons was done at the Massachusetts Institute of Technology and at the University of California. Considerable work along these lines was also done at the University of Rochester. Late in 1941, the University of Rochester obtained a million-volt X-ray generator (fig. 281) for industrial purposes, to make radiographs of armored vehicles such as

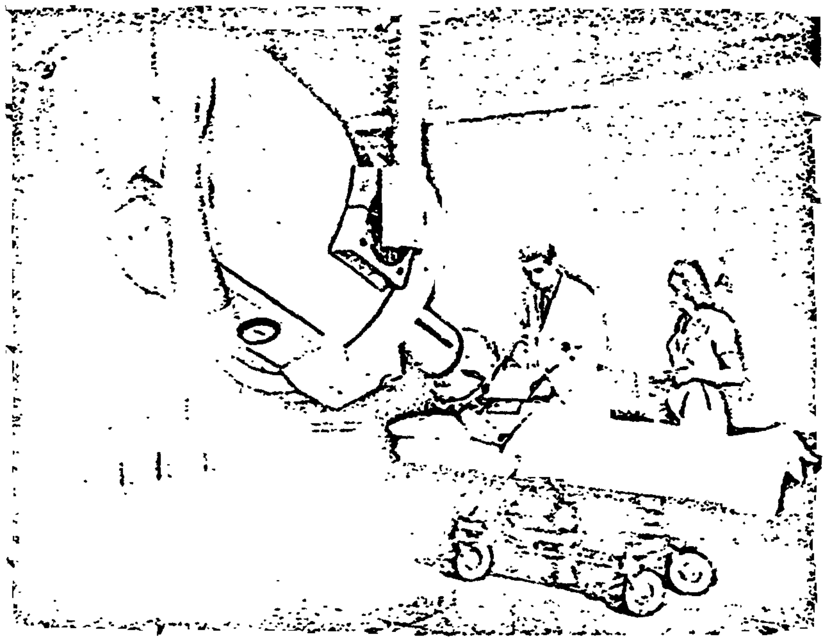


FIGURE 281.—Typical million-volt X-ray machine used early in World War II.

tanks. This work was soon finished and the machine became available for biologic research.

By this time, a considerable amount of work had already been done in the Rochester Medical laboratory, which was under the direction of Dr. Stafford L. Warren. William F. Bale, Ph. D., developed the dipping finger Geiger counter for wet ash techniques and thus made it possible to use the radioactive isotopes made by the local group of physicists (Lee A. DuBridge, Ph. D., Sidney W. Barnes, Ph. D., and Victor Weisskopf, Ph. D., among others), as well as the isotopes obtained from Robley D. Evans, Ph. D., at the Massachusetts Institute of Technology.

Also at the University of Rochester, a number of workers became interested in metabolic tissue effects of radiation and in its genetic effects. These workers included Harold C. Hodge, Ph. D., Don C. Charles, Ph. D., Curt Stern, Ph. D., Luville T. Steadman, Ph. D., and Dr. Andrew H. Dowdy.

GROWTH OF LITERATURE

One final outgrowth of these nationwide research activities played its part in the development of the atomic bomb: Interest in tracer studies led to the rapid growth of several professional journals in this specialized field, including *Radiology*, the *American Journal* of *Roentgenology*, the *British Journal* of *Radiology*, *Acta Radiologica*, and *Strahlentherapie*. The literature of what is now known as radiobiology accumulated rapidly, and frequent collective reviews were published. By 1942, a rather large and comprehensive literature existed, from which could be derived many of the safety policies and principles of operation and protection later put into effect at the University of Chicago Metallurgical Laboratory and elsewhere by the contractors and the Medical Section of the Manhattan Engineer District. Many, of course, had to be devised de novo.

FIRST STAGES IN THE DEVELOPMENT OF THE ATOMIC BOMB

The Uranium Program

At the Conference on Theoretical Physics held in Washington, D.C., 26 January 1939, which was attended by most of the principal workers in this field, reports were made on the work done on the fission of uranium by Otto Hahn, Ph. D., Fritz Strassmann, Ph. D., Otto R. Frisch, D. Ph., and Lise Meitner, Ph. D. Their work was confirmed by telephone during the conference by Niels H. D. Bohr, Ph. D., from his laboratory in Copenhagen, Denmark. Shortly afterward, his observations were also confirmed by workers at Columbia University, The Johns Hopkins University, Baltimore, Md., the University of California, and the Carnegie Institution of Washington, D.C.

By June 1940, 18 months later, the principal facts about fission of the atom had been discovered and were known to the scientific world. A chain reaction had not yet been obtained, but the theoretical possibility, at least, had been demonstrated, and several routes that might lead to it had been suggested.[1]

Meantime, because of their military implications, these developments had

[1] "Actually, it was in March 1939 that Joliot, Hans Halban, and Lew Kowarski, in the College of France, demonstrated that rupture of a uranium nucleus produced by one neutron is accompanied, in addition to the formation of two fission products and corresponding energy liberation, with the emission of several neutrons called secondary neutrons.

"Actually, experience showed that the secondary neutrons which are emitted at very high velocity become, when they are slowed down, more apt to provoke fission of uranium-235. But the method of slowing down rapid neutrons was known. It is sufficient to place about them substances containing light nuclei in contact with which they give up, by successive shocks, a part of their energy in the same manner that a billiard ball is slowed down when it hits against billiard balls of the same size to which it gives up, little by little, its actual force. Consequently, one is thus led to mix with uranium a material called a moderator which slows down the neutrons without absorbing them too strongly. This principle constitutes the basis for the first patent request deposited in France in the beginning of the month of May, 1939. One of these is devoted to the utilization of explosive power of uranium, the others pertain to machines generating energy on the basis of uranium, which were later named piles, or atomic reactors. These patents, the first to have been deposited in the world, have been recognized by many countries.

"The problem of slowing down agents began with hydrogen but the study of mixture of ordinary water and uranium rapidly showed that hydrogen absorbed the neutrons too rapidly to be of value. Finally, the Joliot group arrived at the conclusion that two moderators or slowing down materials could, without a doubt, be utilized in a practical fashion—pure carbon in the form of graphite and heavy water." Extracts from L'Aventure Atomique by Bertrand Goldschmidt, pp. 24 and 27.

been brought to the attention of President Franklin D. Roosevelt, in the fall of 1939, largely on the insistence of Dr. Albert Einstein. An Advisory Committee on Uranium had been appointed as a subcommittee of the NDRC (National Defense Research Council), to review the progress of the research and to keep the President and the Council advised.

The structural changes undergone by the Advisory Committee on Uranium (known as S-1 Section, NDRC) (*4*) are not essential to the story of the relation of radiology to the atomic bomb. When they were completed, late in November 1941, the S-1 Section had been placed under the OSRD (Office of Scientific Research and Development), directly under Vannevar Bush, Sc. D., its Director, and had no further connection with the National Defense Research Council. In its new position, the S-1 Section was administered by James B. Conant, Ph. D., representing Dr. Bush, and Dr. Briggs was its Chairman. With this change, the section became a full-scale operating agency.

The element of secrecy had entered the picture well over a year before, when it became known that the British and German governments were both interested in the possibilities of uranium fission for military purposes. It was for this reason that the Advisory Committee on Uranium became known simply as the Section 1 Committee.

After 1939, by the voluntary, self-imposed action of U.S. and British physicists, there was an almost complete cessation of published articles in the field of atomic fission. In the middle of 1940, the NRC (National Research Council) organized a Reference Committee, with several subcommittees, to control the publication of such articles in every field of possible military interest Papers were forwarded by the editors of scientific and professional journals for review by the committee, which advised against publication if there was any possible military information of significance in them. This was a highly important and very successful action, for by this time little work in the field of atomic fission was being done that was not already incorporated in the OSRD program and therefore under its supervision.

By June 1940, it was known that fission was produced by thermal neutrons in U-235, the rare isotope of uranium. It was not yet known that it was also produced in U-238, the more common isotope. Six months later, active work in the field of fission was underway in 10 or more universities, as well as at the Carnegie Institution of Washington, the Standard Oil Development Co., and the National Bureau of Standards.

The year 1941 was highly critical. Results from various investigations confirmed more surely the important military implications of uranium fission, the work on which was expanded at a very rapid rate. At the request of Dr. Bush and Dr. Conant, several special reports were made by the National Academy of Sciences. When British scientists reported that a U-235 bomb of great power was feasible, Dr. Urey and George B. Pegram, Ph. D., from Columbia University were sent to England for firsthand discussions.

On the recommendation of OSRD, the President agreed to broaden the program, to set up a different organization, to provide funds for the expanded program from a special source, and to effect complete interchange of information with the British.

The "different" organization set up was a Top Policy Group, consisting of the President, the Vice President, the Secretary of War, the Army Chief of Staff, and Drs. Conant and Bush (*4*).

By December 1941, the largest research and pilot projects in the uranium program were concentrated in three universities, Columbia, under Dr. Urey; Chicago, under Dr. Compton; and California, under Dr. E. O. Lawrence. On the 16th day of that month, it was agreed at a meeting of the Top Policy Group that the OSRD should press on as fast as possible with the development of the fundamental physics of atomic fission and with the engineering, planning, and, particularly, the construction, of pilot plants. Later it was also agreed that the Army should take over the whole program as soon as full-scale construction was started. This stage was reached on 18 June 1942.

When all S–1 Section activities were reviewed in April and again in May 1942, various methods of producing material for the atomic bomb were discussed. It was the decision of the Section 1 Committee that, since there was no certainty of success with any single large-scale method, no chances should be taken and all feasible methods of producing fissionable material should be explored (*4*).

During this period of development, the committee was perpetually faced with two anxieties: 1. Would the atomic bomb be a decisive weapon? 2. How much were the Germans doing in this field? In the satisfactory answers to these questions lay the justification for the withdrawal for the development of the bomb of highly critical materials and always short manpower from the remainder of the national military effort.

Establishment of the Manhattan Engineer District

In May 1942, OSRD S–1 Section was terminated and was replaced by a smaller OSRD S–1 Executive Committee, with Dr. Conant as Chairman (*4*). While Dr. Bush alone had the authority to establish OSRD policies and commit OSRD funds, he ordinarily followed the recommendations of this committee.

In a report prepared by the S–1 Executive Committee in June 1942, it was stated that kilogram amounts of either U–235 or plutonium (Pu–239) would be very highly explosive and would be equivalent to several thousand tons of TNT; that the detonation time could be controlled; that it would take large production facilities to produce the necessary fissionable material to make such a bomb; that the bomb materials could be produced by at least four methods (three using U–235 and the other Pu–239); that all four methods should be employed because the urgency of the situation made it unsafe to rely on any single method; and, finally, that with adequate funds and priorities, the project could probably be completed in time to be of military

FIGURE 282.—Maj. Gen. Leslie R. Groves, Commanding General, Manhattan Project.

value in the war then in progress. The project, however, would be a drain on, and would interfere with, other war activities.

The report just summarized was sent by Drs. Bush and Conant to Vice President Henry A. Wallace, Secretary of War Henry L. Stimson, and Army Chief of Staff Gen. (later General of the Army) George C. Marshall on 13 June 1942 (*4*). All approved it. On 17 June 1942, it was sent by Dr. Bush to the President, who initialed it. A copy of the report was then sent by Dr. Bush on 19 June 1942 to Brig. Gen. (later Lt. Gen.) Wilhelm D. Styer, GSC, Lt. Gen. Brehon B. Somervell's Chief of Staff.

The day before, Col. (later Brig. Gen.) James C. Marshall, CE, was instructed by the Chief of the Corps of Engineers to form a new district in the Corps to carry on special work assigned to it (*4*). This district, designated the Manhattan Engineer District, was officially established on 13 August 1942. The special work assigned to it, the development of the atomic bomb, was labeled, for security reasons, the DSM (Development of Substitute Materials) Project (*4*).

On 17 September 1942, Secretary of War Stimson assigned Brig. Gen. (later Lt. Gen.) Leslie R. Groves (fig. 282) to be in complete charge of all Army activities of the DSM Project (*4*). General Groves thus became commanding general of what was soon called the Manhattan Project, and which was the planning headquarters of the entire program. The Manhattan Engineer District was its major operating arm.

General Groves was specifically directed by the President to take all

means to insure the security and secrecy of this project. Since the OSRD report of 13 June had been approved by the President, General Groves, on that basis, asked for, and received, the highest priorities for procurement of material. Without those priorities the program could not possibly have succeeded.

The research and development contracts of the OSRD were formally turned over to the Manhattan Engineer District on 1 May 1943 (*4*).

ESTABLISHMENT OF THE MEDICAL SECTION MANHATTAN ENGINEER DISTRICT

During the fall and winter of 1942–43, it became evident that the Manhattan Engineer District must develop an extensive and detailed medical safety program for its uranium pilot and production programs, which were now beginning to be spread all over the country, but particularly for the secret cities (p. 832). The Clinton Engineer Works was being organized to develop the 58,800-acre site at Oak Ridge, Tenn., whose purchase had been authorized in September 1942. At Hanford and Richland, a site had been selected for the operation of the Hanford Engineer Works, and construction on its 420,000 acres would begin in April 1943.

Withdrawing medical personnel assigned to the University of Chicago Metallurgical Laboratory (p. 864) for tours of duty in the Manhattan District Office was clearly no answer, and in March 1943, under conditions of strictest secrecy (p. 846), Dr. Stafford L. Warren, Professor of Radiology at the University of Rochester School of Medicine, was engaged to advise the District Engineer on "special materials."

Dr. Warren's first consultation in the New York office of the Manhattan Project with Maj. (later Lt. Col.) Hymer L. Friedell, MC, who had been assigned to the new Manhattan Engineer District (p. 839), was very general. Major Friedell, who displayed a knowledge of the new field of isotopes not common in most recent residents in radiology, questioned Dr. Warren, without giving him any reasons, concerning shielding against radiation, protection against radioactive dusts, safe standards of exposure, and similar matters. Dr. Warren replied that there were no experimental data upon which answers to most of these questions could be based. Major Friedell inquired whether some of the experiments necessary to provide the answers could be carried out at the University of Rochester, in secret, if laboratory facilities and funds were provided. Would Dr. Warren produce an outline for certain specific experiments within the next 2 weeks? As soon as his proposals could be examined and it could be determined that they would meet the needs of the project for which they were designed, a contracting officer from the Manhattan District would be sent to the school to authorize construction, which would be begun as soon as possible.

In the meantime, Major Friedell continued, a hospital was being planned,

FIGURE 283.—Lt. Col. (later Maj. Gen.) Kenneth D. Nichols, CE, at Oak Ridge Headquarters for the Manhattan Engineer District. During working hours the desk was piled high with reports, all highly classified; it was stripped for this picture, as it was every night. There were severe penalties if any papers were left out or if desks or safes were left unlocked, even in the most closely guarded areas.

and decisions must be reached concerning its location and its size. If Dr. Warren would be willing to spend 3 days the following week looking over the site that had been tentatively selected for it, Major Friedell would fill him in on "some things." Lt. Col. (later Maj. Gen.) Kenneth D. Nichols, CE (fig. 283), Chief Operating Officer for the Manhattan Project under General Groves, who came into the office about this time, said that the trip would impress Dr. Warren with the importance of the project and would convince him of the necessity of staying with it, even though its specific nature could not yet be disclosed to him.

The inspection of the hospital site at Oak Ridge duly took place (p. 872), and by the end of May 1943, most of the information about the uranium program had been disclosed to Dr. Warren. He accompanied Major Friedell on inspection trips to plants in New York City, Buffalo, and Niagara Falls, in which uranium ore concentrates were being refined in large quantities and in which there were two problems, the toxicity of uranium salts and the radiation hazards in the discard (p. 854).

By 1 August 1943, the medical activities of the Manhattan Engineer District had become so unwieldy that it was necessary to define them more clearly. On 10 August 1943, Colonel Nichols, then deputy District engineer, created the Medical Section, MED, with Major Friedell as executive officer and Dr. Warren as civilian consultant to him. Capt. (later Maj.) John L. Ferry, MC, was also assigned to the Medical Section.

In October 1943, Dr. Warren reported to General Groves that the organization of the Medical Section, MED, was essentially complete and that he could no longer function effectively in a civilian status. On 3 November 1943, he was commissioned Colonel, MC, AUS, and was appointed Chief of the Medical Section, MED, and medical advisor to the commanding general, Manhattan Project.

Later in November 1943, the office of the Medical Section, MED, was moved to Oak Ridge, where it was operated under Colonel Nichols, then District Engineer. The Medical Section functioned here until the end of the war, with Colonel Warren as Chief, Major Friedell as deputy chief, and Capt. (later Maj.) Robert J. Buettner, MAC, as administrative officer.

Mission.—The mission of the Medical Section, MED, outlined by Colonel Nichols when it was created, covered the following functions:

1. The conduct of, arrangement of, supervision of, or liaison with, such research work as is considered necessary for carrying out the functions of the Medical Section.
2. The determination of health hazards and the institution of protective measures against them in all operations of the Manhattan District.
3. The instruction of contractors and area engineers concerning the necessity of safeguarding the health of their personnel and making proper use of hospitals and related services.
4. Assistance to, cooperation with, and periodic inspections of, the area engineers' and contractors' programs, to be certain that the protective practices directed were being carried out.

The order outlining these functions of the Medical Section, which was deliberately vague for security reasons, was distributed to area engineers in charge of contractors, whose operations now covered most of the northern and western parts of the United States.[2]

The mission of the Medical Section, Manhattan Engineer District, thus concerned three main responsibilities:

1. The coordination of the biomedical research programs in the universities. This was one of the most important functions of the Medical Section. The rapid development of new information made it imperative that channels of communication be developed among radiologists, physicists, engineers, contractors, and university research groups. The Medical Section helped to disseminate this information and thus expedited the development of the safety programs that were introduced in the various stages of the production program.
2. The industrial safety procedures required for individual on-site and

[2] The document referred to remained classified when this volume was ready to be published, and its title, therefore, may not be given here.—A. L. A.

off-site contractors in various locations, and the inspection program that insured their observance.

3. The medical care and public health protection of populations at the secret sites.

Procurement of supplies for hospitals and for the medical programs, both on-site and off-site, was never a problem, since it was covered by the Manhattan Engineer District priority, about which no questions were ever asked.

PERSONNEL AND TRAINING

Prewar Training

It was extremely fortunate that training in radiology underwent a considerable expansion just in time for the young men who were to play an essential part in the later development of the atomic bomb to take advantage of it. In most teaching institutions the residency in radiology had been lengthened to 3 years, and in a few to 4 years. Also a year of research was being discussed as a residency requirement (p. 832) and was attracting an occasional graduate student.

It is difficult to realize today (1965, some 25 years later) how little knowledge about radiation was available in 1940 and how important these few well-trained pioneers were to the successful production of the atomic bomb over the 4-year period in which frightening amounts of radioactive material were handled in absolute safety. In 1940, a curie (1 gm.) of radium was considered a dangerous amount and few institutions owned as much. A few years later, the megacurie, equivalent to 1,000 kg. of radium, was to become commonplace.

The development of the Lawrence cyclotron at the University of California in Berkeley, and the excitement created in the biologic world by the many possibilities opened by the availability of radioactive isotopes, brought not only young physicians but also physicists, biologists, and biochemists into the field of radiology.

By the late 1930's, the need for physicists as permanent, full-time members of cancer therapy teams had become indisputable. The evolution was gradual. Not infrequently the physicist first entered the picture when he prepared radon seeds from radium salts, a technique by then employed in many large hospitals. When a new high energy X-ray source was installed in an institution, the physicist was needed to keep the equipment in operating condition for the radiologist, who soon came to feel the need for the help the physicist could give him.

A less frequent sequence began in reverse, with the exploration of high energies in a department of physics, with the gradual involvement of the radiologist in the project. Which method of association occurred makes no difference now. What is important is to realize that for perhaps a decade before the United States entered the war, a gradual synthesis of physics and biology, which was both exciting and productive, was developing. The result was the evolution of a new field of science, biophysics, and the widened education of young scientists who matured out of their Ph. D. courses and of young physicians who completed their residencies in radiology and medicine just in time to be incorporated in the program of the Medical Section, Manhattan Engineer District.

At the University of California during the 1930's, many graduate and postdoctoral fellows worked on radioactive emitters on the Berkeley campus. In the Medical School of the University, on the San Francisco campus, the work of Dr. J. H. Lawrence has already been mentioned. Dr. Friedell was trained in Dr. Stone's Department of Radiology there. Another worker in the program was Dr. Joseph G. Hamilton, an imaginative and brilliant neurologist, who had an avid interest in experimentation. His association with the Stone group proved ideal for them as well as for him. At this time, Dr. Stone was deeply concerned with the hazards, measurements, dosages, and effects of X-rays and neutrons in his work with the new Sloan generator. Dr. J. G. Hamilton, in return for obtaining isotopes from the Lawrence cyclotron for his own work, took on the supervision of the medical health and safety of the physicists, engineers, chemists, physicians, and technicians working in the rapidly expanding group on the Berkeley campus. He set the guidelines and the exposure standards and instituted the protective measures against the neutrons and other radiation emitted by the cyclotron as well as against the radioactive emitters produced on the cyclotron target. He also participated in the development of safe handling practices for the new radiochemical ("hot") extraction purification procedures. He devised micromethods and other procedures for biologic testing of new radioactive elements as tracers. His exploitation of radioactive isotopes and their biologic and biochemical properties was highly imaginative and even spectacular (*5*). He was an excellent teacher, and by the middle of the 1930's he had begun to attract to the University a number of good graduate students, postdoctoral fellows, and technicians who later participated in the atomic bomb program, among them Kenneth G. Scott, Ph. D., and Cornelius A. Tobias, Ph. D.

Many well-trained young physicists were also produced at the University of Chicago by the Compton group. These men (among them, David Rose, D. Sc., Herbert M. Parker, Ph. D., and Ernest O. Wollan, Ph. D.) devised most of the instruments necessary for both the small and the large quantities of radiation of all sorts used in the biologic and safety work of the whole program.

Similarly well-trained men were available at the University of Rochester. In 1943, when the high-voltage generator unit was converted and expanded for use in the intensive program of biologic research then under way, the program could be begun at once on tolerance doses of X-ray (Dr. Dowdy); on genetics and tissue effects of radiation (Dr. Stern and Dr. Charles); on toxicology and standards of safety for noxious chemical substances (Dr. Hodge); and on instruments (Dr. Bale).

Procurement of Medical Personnel

The procurement of suitable personnel for the Medical Section, MED, constituted a serious problem, though it was less serious than it might have been: Fortunately, both the civilians and the medical officers who first became concerned with health and safety matters were unrestricted in their point of view. They promptly recognized the broad implications of large-scale uranium operations in almost every field of medicine, and they had both the intelligence and the courage to anticipate the needs of the almost incredible expansion of the program soon to occur.[3]

Since the medicobiologic program of the Manhattan District was a late (1943) development in the general organization for the war effort, it was feared in many scientific circles that the organization of an expanded research program in radiation and radioactivity, both new fields, would be almost impossible because of lack of manpower. This fear proved groundless, for several reasons:

1. Many competent men, especially among younger physicians and scientists, had not yet been recruited for service because their dedication to their work in cancer, metabolism, and similar fields was so great that their skills did not seem particularly useful in the war effort.

2. The accelerated educational program in the medical schools was still not fully underway in 1943, and the schools had not yet been as completely stripped of their faculties by Selective Service calls as they were in 1944 and 1945.

3. A small but hard core of experienced personnel was available, as just pointed out, because of the fortunate interest that had developed in tracer experiments and similar studies just before the war.

The professional radiologists who first entered the Medical Section of the Manhattan Engineer District were recruited chiefly from the field of cancer therapy, in which they had been interested in high energy radiation, rather than from the diagnostic radiology group. They included Dr. Simeon T. Cantril, Dr. Dowdy, Dr. Friedell, Dr. Stone, and Dr. Stafford L. Warren. Others were specialists in internal medicine (Dr. J. H. Lawrence, Dr. John B. Hamilton, Dr. Leon O. Jacobson, and Dr. Louis H. Hempelmann). Still others were from the basic biologic sciences (Kenneth S. Cole, Ph. D., Karl Z. Morgan, Ph. D., Dr. Parker, Dr. Bale, Dr. Hodge, and Dr. Scott). No matter what their previous specialty, all were interested in using radiation or isotopes as tools to explore basic mechanisms in biologic systems. As the project became more complex, experts from other fields of medicine were brought in, and eventually radiologists constituted only a relatively small portion of the personnel.

Medical Corps officers.—Medical Corps officers were used as far as possible in the secret sites at Oak Ridge, Hanford, and Los Alamos, for two

[3] See footnote 2, p. 843.

reasons. The first was that it was impossible to find civilian physicians with the required quality of training in large enough numbers to staff the hospitals and clinics at these sites. The second reason was that medical (military) officers were more desirable, for security reasons, in locations in which accidents with radiation exposure might occur.

In September 1943, therefore, an arrangement was worked out by correspondence between the District engineer, Clinton Engineer Works, Oak Ridge and The Surgeon General, to "commission or provide commissioned officers and funds" for the medical and dental care of military personnel wherever facilities for such care were available. Medical, dental, veterinary, and administrative officers would be supplied as requested (as well as medical supplies) for the military detachments assigned to the Manhattan District, without disclosure of their destination or mission. Efficiency reports would be retained by the Manhattan District. For security reasons, no transfers would be made into or out of the District without the approval of the District engineer.

Col. Arthur B. Welsh, MC, was appointed by The Surgeon General to provide liaison between his office and the Manhattan District. In 1945, Colonel Welsh was replaced by Lt. Col. Carl C. Sox, MC. Major Friedell, representing the Medical Section, MED, conferred with Colonel Welsh on the procurement of personnel as the need arose. On the advice of Maj. Charles E. Rea, MC (p. 873), as many officers as possible who were to serve in a given site were secured from the same medical school residency programs, so that they would already know each other and would be used to working together. The policy was very effective, one reason being that since the families were already acquainted with each other, there was less loneliness and a better esprit de corps is these isolated assignments.

On-the-job training expedited the production of special investigators, supervisors, and monitors, as well as the special workers who were in charge of the complex protective techniques considered necessary for safety.

SECURITY

As soon as the Manhattan Engineer District began to operate on a large scale, it became apparent that safety practices were a primary requirement, quite apart from humane considerations, for two reasons, both of which arose from the necessity of maintaining absolute secrecy:

1. If scientists or workers in any part of the project should receive enough radiation, or should absorb enough radioactive material, to produce physiologic damage, with subsequent clinical manifestations, or should die from the effects of the damage, it would be impossible either to keep the project secret or to procure enough employees to carry on with it.

2. If controls over radioactive materials in effluent air and water and on contaminated clothing were not strict, radioactivity might become measureable in the surrounding community and the knowledge might leak out that a

secret government project was operating on a large scale with radioactive materials.

Security was therefore, both directly and indirectly, the original driving force that made the most hazardous, and probably the single largest, industry under one control in World War II the safest of all wartime enterprises.

The assignment of special research projects in the program to a number of different laboratories, in accordance with their special capacities and past experience, made it possible to restrict and divide the whole program into compartments without disclosing its goal and without the integration of any special research projects with the whole project. This principle was so strictly followed that each participant in the program knew only enough to carry out his own assignment. The actual names of critical materials were never used. The code names or numbers for them used by a local contractor or research group might be known only to the area engineer, and he, in turn, might use for the same materials a different code, known only to the District engineer.

The pace and pressure were usually so great that there was little time for speculation, and the general attitude of the medicobiologic research workers was "If this is all we need to know, we don't want the responsibility of knowing any more."

The length to which security measures were carried is evident in the method used when Dr. Warren was first invited to discuss becoming civilian consultant "on special materials" to the Manhattan Engineer District. In the middle of February 1943, he was invited by Albert K. Chapman, Ph. D., vice president and general manager of Eastman Kodak Co., Rochester, N.Y., to have lunch with him, General Groves, and Colonel Marshall at the Rochester Club. During luncheon, Dr. Warren was asked by Dr. Chapman to describe some of his work with radiation and isotopes, and, particularly, to describe the million-volt X-ray equipment for X-raying Army tank castings (p. 835). Eastman Kodak Co. was involved in this work. The two officers expressed themselves as particularly interested in the shielding of this apparatus.

After lunch, Dr. Chapman took his departure, after first advising Dr. Warren to agree to do whatever the officers asked of him. The officers then took Dr. Warren to a private room, where one of them closed and locked the door and closed the transom while the other looked into the closet. Both of them then looked out of the closed window, and, when they sat down, there was a moment of quiet, during which they seemed to be listening.

After these preparations, General Groves asked Dr. Warren if he would consider working on a very important medical program for the Government. Dr. Warren replied that he was already committed to the hilt with teaching, OSRD work, and the tank castings program he had described at lunch. He was asked if he could take on more important research in his own field at the University if he were provided with research funds in adequate amounts and a laboratory building, and if a replacement could be found for him in his OSRD work. He would also be needed on occasional trips to look over certain research and other programs. Would he be willing to become a consultant for a trial period of several months? It was exceedingly important that he should, but the work was so confidential that nothing could be explained to him until he had accepted the offer.

Dr. Warren was given a number to call in New York, to arrange for a trip there to talk over the matter with another officer (Major Friedell) already on the staff of the project. He was told to talk to no one about the meeting with General Groves and Colonel Marshall except Dr. Alan Valentine, President of the University of Rochester, Dr. George H. Whipple, Dean of the Medical School, and Dr. Chapman. When they left, the officers shook hands with Dr. Warren and told him that if they had not expected him to become a consultant in the project they would not have met with him.

Luncheon had been brief, and the discussion after it had not lasted more than 15 minutes. The psychologic impact of the technique used was enormous, and the preparation for the interview, Dr. Warren found later, had been thorough. The two officers had called upon President Valentine, asked his permission to enlist the services of one of his faculty, and given him the name of Dr. Conant, President of Harvard University, as their reference. When Dr. Valentine phoned President Conant, he was told that the project in question was "a very important war program," and that he should agree to whatever the officers had asked of him.

Under these circumstances, Dr. Warren became a consultant to the Manhattan Engineer District on 2 March 1943, within 2 weeks after the original interview.

Major Friedell, then a civilian, was engaged in much the same manner. He had worked with Dr. Stone's group at the University of California in San Francisco, and in early August 1942, he was hesitating between a third year of training or volunteering for the Medical Corps; he was unwilling to enter service unless his training and interest in radiology could be utilized. At about this time, the laboratory was visited by Colonel Nichols, assistant to Colonel Marshall in the Manhattan Engineer District, who was reviewing OSRD contracts held by Dr. E. O. Lawrence (p. 833). Colonel Nichols promised Dr. Friedell that if he would accept a commission in the Medical Corps at once, he would be very helpful in a program that Dr. Stone had already agreed to join (the University of Chicago Metallurgical Laboratory). Dr. Friedell accepted the proposal without any more information concerning it, was commissioned at once, and was assigned to the Manhattan Engineer District as its first medical officer. Late in August 1942 he was sent to Chicago to join Dr. Stone.

The secrecy imposed on the officers and civilian workers in every phase of the development of the atomic bomb extended to their families. When Dr. Stafford L. Warren was commissioned in the Medical Corps in November 1943 and was assigned to Oak Ridge, his family, for security reasons, moved there also, as did the families of many of the other workers there. Mrs.

Warren did not know until after the war had ended what her husband or any of his associates were doing, and other wives were similarly ignorant. In the beginning, there was no social life at all in the 58,000-acre barbed wire enclosure. Families were allotted houses on the basis of the number of children they had, not by rank. Children were registered in school by their first names only. No one was permitted to say whence he came or what he was doing. Pseudonyms were often used. Physicist Arthur Holly Compton was Mr. Holly. Dr. Urey was Mr. Smith. When some one indiscreetly mentioned heavy water at a dinner at which "Mr. Smith" was present, Mrs. Warren realized who their guest was, though she had no idea what he could have in common with her husband, whose specialty was radiology.

The men kept quiet about their work because they were ordered to. Their wives and families kept similarly quiet about everything, for fear, or as a matter of honor, or because they really though it was better to know as little as possible. Dr. Warren was guilty of one breach of security: His two teen-age sons rifled his pockets, after one of his trips, for match folders, which, when they laid out, enabled the boys to trace his journey from Rochester, N.Y., to Hanford, Wash. All that he said to them, Mrs. Warren recalls, was "touché," but "something in the way he said it made them know that this time it wasn't a game of cops and robbers."

DOSAGE TOLERANCE

The first quantitative statement concerning tolerance dosage of X-rays, later referred to as the MPD (maximum permissible dose), was made in 1934, by the International Commission on Radiological Protection. It was set at 0.2 r per day (*6*). In 1936, the U.S. National Committee on Radiation Protection and Measurements set the level at 0.1 r per day, a level that was maintained throughout the war.[4] In 1938, the same Committee also set a "*permissible body* burden" for radium at a level of 0.1 microcurie. Although these levels were accepted by the national professional organizations concerned with radiology, it was clear to all that they were speculative end-points, not substantiated by any existing data.

Therapeutic Doses

During the 1930's and early in the 1940's, commercial designs of X-ray machines were greatly improved and high energy radiation sources became more available. As a result, there was renewed interest in the physiologic

[4] In 1948, the tolerance dosage was reduced to 0.3 rem per week, and in 1957 to an average of 5 rems per year. The permissible radium level was not changed. At the present time (1965), the radiation exposure standard has been reduced from 0.1 r per day for a 5-day week to 0.3 r (0.3 rem) for a 5-day week, or 5 rems per year. There is still, however, no satisfactory body of substantiating experimental data to support this level. Satisfactory evidence of the safety of these doses would require extensive, careful, fundamental research carried to a significant end-point through the life time of a large species.

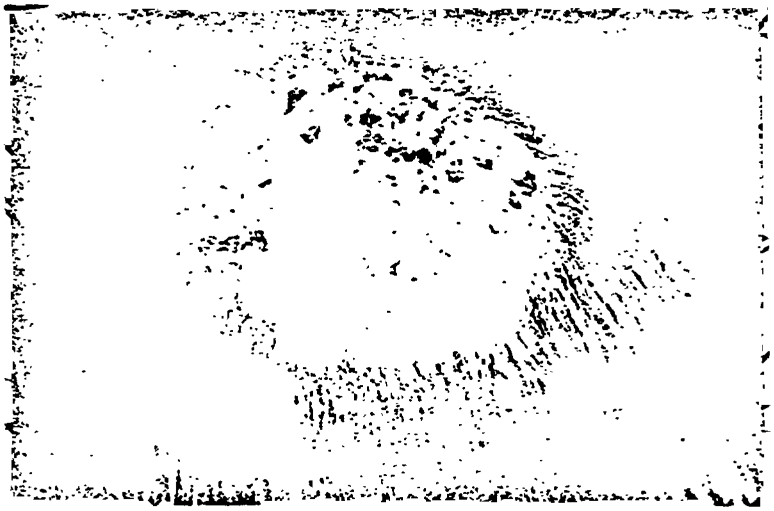


FIGURE 284.—Typical epilation and scarring of scalp after radiation therapy for ringworm.

effects of radiation of various intensities on organs and tissues of varying sensitivities. A further result was that it became possible to give higher depth doses for deep-lying tumors with, at the same time, less severe skin damage at the site of treatment.

Cancer clinics all around the world had for a long time been using various X-ray techniques, with and without surgical removal of the cancer. They were also using combinations of radium and X-rays over limited areas of the neck, pelvis, lip, and other parts of the body. Courses of treatment for carcinoma of the lip extending over 6 weeks and totaling 4,000 r were not unusual. Healing was quite satisfactory. All areas so treated, however, were very small. Larger areas were treated much more conservatively. Injuries of the bowel and bladder were not infrequent sequelae of the first attempts at pelvic irradiation for cancer of the cervix, with 200-kv. X-rays alone or in combination with applications of radium to the cervix.

Recognized dangers of radiation included cataracts (7); loss of hair after treatment for ringworm of the scalp (fig. 284) and at other portal sites and its return with pigmentary and structural changes; erythema of the skin with pigmentary changes, atrophy, and scarring; desquamation of cartilage and even of bone; damage to the bowel and bladder; and temporary destruction of lymphoid and splenic tissues. All of these sequelae were well known, but eration, but they were also followed by improvement in the 5-year cures (control) over previous results.

As time passed, dosage comparisons became possible because of the introduction of standardized dosimeters; the Victoreen r-meter was most commonly used in U.S. clinics. All these instruments and radiation source standards could be calibrated in the Radiation Laboratory of the National Bureau of Standards (*6*). This laboratory, which was established in 1927 as the result of pressures by the radiologic profession, was able to calibrate instruments after 1929. In 1928, it employed three persons; in 1960 it employed 100.

By the time the United States entered World War II, a large body of knowledge had accumulated in the cancer clinics of the country, as well as in Canadian and British hospitals, from direct clinical trials in advanced and hopeless cancer with higher and higher energy X-rays (from 200 to 1,000 kv.) (*9–13*), and with gamma rays of radium salts and radon seeds and neutrons (*14, 15*). The knowledge was empirical, however, and it concerned only restricted areas of body and specific organs, including the lips, tongue, skin, especially of the face, larynx, breast, and cervix.

Experimental Studies

In April 1942, when Dr. Warren was serving as civilian consultant to the Manhattan Engineer District but still had not been informed of all the details of the program which it had underway, he and Major Friedell agreed at one of their conferences that certain experiments should be undertaken at the University of Rochester Medical School, these investigations to include tolerance levels and genetic low level radiation exposure (daily exposures at the 0.1 r per day level), as well as a search for improved instruments and the development of techniques to carry out the tolerance studies. No explanation was given of the need for such studies, and Dr. Warren, convinced that they must be of great importance, asked no questions.

An office was promptly established at the University of Rochester, and an area engineer, Capt. (later Lt. Col.) E. L. Van Horn, CE, was assigned to the laboratory, which was enlarged to accommodate the planned experiments. A million-volt X-ray machine was already available (p. 835). The studies just mentioned were carried out, as well as studies on the deposition of heavy metals in bones (Dr. Hodge) and on instrumentation (Dr. Bale).

Early in 1944, Dr. Dowdy began to test doses above and below 0.1 r per day for 5 days a week in primates, dogs, rabbits, rats, and mice; his studies included genetic observations. Experiments on fertility and genetics were carried out by Dr. Stern on *Drosophila* flies and by Dr. Charles on mice. In 1945, somewhat similar studies were carried out at the National Institute of Health by Egon Lorenz, Ph. D., who used very small doses from a radium source over long periods of time.

Another series of experiments was carried out at the University of Washington School of Fisheries by Lauren R. Donaldson, Ph. D., with Columbia River salmon and trout. X-rays were employed because there seemed no feasible way of utilizing either mixtures of internal emitters from the Hanford piles or long-term exposures. Massive single doses were therefore employed at 180 kv. over a range of 20–100 roentgens in both males and females and in artificially fertilized eggs. Some interesting genetic observations were just beginning to be made when the experiments were terminated with the end of the war.

Maximum Permissible Dose

Up to 1943, not much attention had been paid in the uranium program to MPD standards because the quantities of radioactive materials being produced were relatively very small. With the expansion of the program and the development of the chain-reacting piles, it became necessary to establish shielded and protected working conditions. The first consideration was the maximum permissible dose. After extremely serious consideration of added costs and probable delays if levels should be changed at any later time, it was the official decision that 0.1 r per day should be the total external body maximum permissible dose.

A large factor of safety was required because of the very large extrapolation of findings from the fly or the rat or mouse to man. There was therefore extensive consultation before the MPD and other standards were determined. It is interesting and gratifying to realize that the positions taken in 1943 are for the most part still (1965) valid. Postwar research has refined some of the end-points by less than an order of magnitude, and more is now known of the laten effects of radiation than was then even suspected, but there has been no major alteration in any of the postu ates then employed.

RADIATION AND OTHER HAZARDS

In May 1943, Dr. Warren and Major Friedell attended a conference with Dr. Stone's group at the University of Chicago, at which the wide ramifications of the Metallurgical Laboratory there were reviewed—and most of the facts concerning the development of the atomic bomb were disclosed to Dr. Warren for the first time.

A great deal of experimental work had been carried out by the Chicago group since Dr. Stone's arrival 9 months earlier. The Fermi pile had gone critical on 2 December 1942, and the physicists and chemists engaged in the project, working under Dr. Compton, together with the engineers of the E. I. du Pont de Nemours & Co., were just beginning to design the pilot plant to be built at Oak Ridge (the Clinton Engineer Works). Although the designs for the piles at Hanford were barely started, it was already evident that the radiation problems of the larger piles would be similar, but vastly greater, than the problems of the pilot pile at Oak Ridge.

Uranium X1 and X2

All four methods for producing material for the bomb from uranium, as either the common or the rare isotope (p. 839) or as the new plutonium were employed at Oak Ridge. Three of these methods were assumed to carry only the hazard of radioactivity caused by constant accumulations of uranium X1 and uranium X2. For every ton of uranium metal (element) produced, or for its equivalent in ore or concentrates, some 40 curies of X1 and X2 were formed naturally every 90 days. Discards formed a special problem when either extraction of uranyl nitrate was employed, and their storage would obviously present major difficulties if and when the production rate became greater, particularly if the discards contained radium salts, as they frequently did.

The three isotope separation methods that accumulated uranium X1 and X2 were the electromagnetic separation process designed by E. O. Lawrence (Y-12); the selective filtration or barrier process designed by Urey (K-25); and the thermal diffusion separate schedule designed by Abelson (S-50). The fourth production method, the Chicago pilot pile (reactor, X-10) or chain-reaction procedure, was designed to produce plutonium (Pu-239) from uranium (U-235). In the course of the chain reaction, a great many radioactive emitters were produced, each of which had to be regarded as a possible hazard. In addition to the risks of external exposure of workers, there also had to be taken into consideration the possible ingestion or inhalation of these substances (p. 862), or their introduction into the body by some other means, or their loss as stack effluent into the air or into the cooling water systems.

Contamination

When radioactive tracers began to be used widely, problems of contamination began to show up in the laboratory, and waste disposal procedures had to be designed. Since radiologists were already aware of the hazards of repeated low level exposures to radiation, there was already a good deal in the literature about shielding and protection from increasingly higher energies of the diagnostic and therapeutic beams by the use of barium plaster and lead-lined and concrete walls in new hospital installations (*10, 16–20*). Some standard criteria for levels of protection were in order, since protective shields in the plants were expensive, and their weight created structural problems.

Ashes and Wastes

A great deal of work was carried out in the laboratories at Oak Ridge on the safe handling of radioactive ashes and waste products left after the extraction of plutonium from U-238. Even though the extraction was accomplished by remote control, with heavy shielding, occasional hazards had to be circumvented. New designs and procedures would be necessary to eliminate them in the Hanford operation, in which the amount of radioactivity would be fantastically greater than at Oak Ridge and the Chicago Metallurgical Laboratory. Moreover, the hazards, even with uranium X1 and X2, differed from site to site in the kind of discards and the amounts.

The area engineers usually solved these problems for a group of industries by stockpiling the discarded waste radioactive materials in a carefully selected location, which was not subject to flooding or excessive erosion from heavy rainfall, so that contamination would not be be introduced into a river or lake that was an actual or possible water supply. Some sort of barrier was erected around the location used. In other instances, waste materials were stored in abandoned reservoirs, with the expectation that some better solution would emerge after the war.

The ashes from the piles at Hanford and the radioactive material left when the uranium was bombarded in them were another matter. By the time the extraction had proceeded long enough to produce the material necessary for a number of bombs, there would be a sizable storage problem for these materials, both in solution and in precipitates.

A number of wells were drilled to test the isolation of various areas in the Hanford site, to be certain that the stored materials would not enter either the water table or the Columbia River. At both Oak Ridge and Hanford the best solution was the building of huge underground reservoirs, with double concrete walls.

Dusts

Dusts were important for two reasons:

1. They were radioactive and therefore might cause damage from the emitted radiation if they were inhaled or ingested.
2. They were often toxic.

Chambers in which animals could be exposed to dusts and fumes were not well developed at this time, and there was no precise way of calibrating the dosage received by an animal exposed at a presumed concentration of dust in such a chamber. Further uncertainties were introduced into the experiment because of the animals' habit of licking their fur after the exposure, thus complicating the chronic experiment by the amount of material swallowed.

At Berkeley, Dr. J. G. Hamilton and Dr. Scott solved this particular difficulty by giving rats a single exposure of short duration, with only the head completely exposed. No solution, however, was found for the technical problem of repeated daily exposures.

Inhalation Hazards

Studies on inhalation risks were carried out chiefly by Dr. Hodge at the University of Rochester and Dr. Albert Tannenbaum at Michael Reese Hospital in Chicago. Two important conclusions emerged from their work:

1. A considerable excretion of inhaled particulate matter into the throat was caused by the movement of cilia in the larger bronchi.

2. A great deal of potentially dangerous material was therefore probably absorbed by ingestion rather than by inhalation.

Great reliance was placed on the results of chronic toxicity experiments performed by feeding test salts to mice and rats over 30- to 90-day periods at low dosage levels. These experiments were usually carried out simultaneously in the laboratories at Chicago and Rochester, with only minor procedural differences, so that one series would serve as a check on the other and the experiments would not have to be extended unduly or repeated.

Other Hazards

Radiation was not the only hazard encountered in the development of the atomic bomb:

1. Uranium hexafluoride, an important form of uranium employed in very large amounts in several stages of the program, also introduced hazards. Elemental fluorine gas used in its manufacture was found to ignite and burn up valves if a speck of carbon were left in the valve seat or aperture. Some short-term but extensive experiments showed that the risk here was not from the effects of inhaling the gas but from the high temperature of the fluorine flames. Hazards to the local population could occur if large amounts of fluorine or fluorides were to be discharged in effluents in any quantity. These hazards were studied, and contractors were advised of the precautions that should be taken to avoid them.

2. Beryllium was fabricated in large amounts in one stage of the process, and several acute pulmonary-circulatory injuries occurred before this risk was realized and controls and preventive measures were introduced.

3. The toxicity and toxicology of a great many new solvents was entirely unknown, and all of them had to be tested quickly. Since many of them were employed only to clean pipes and other gear during the installation of plant equipment, special precautions were developed for this single handling, but no extensive toxicity studies were made.

4. Carbon tetrachloride, which was used as both a cleaning and a reacting agent in various chemical chlorinating reactions, was an occasional hazard, particularly if it came into contact with a hot plate or gas and produced phosgene.

DEVELOPMENT OF THE HEALTH-SAFETY PROGRAM

Concept of Safety Precautions

Several fortunate circumstances combined to make it appropriate and possible to introduce safe practices from the very beginning of the uranium program, although they were somewhat crude as compared to the more refined practices later introduced:

1. Industry had long recognized the wisdom of protecting workers from noxious and hazardous materials (*21–26*), and compensation insurance against injury in hazardous occupations was well established.

2. All radiologists and scientists, from reports in the literature or their own past experience, were aware of the risk of exposure of the body to penetrating radiation, even in small amounts (*27*). Bone and marrow damage had been reported by Martland and his associates in 1925, in workers on radium-painted dials (*28*), and similar hazards from inhalation of radon in laboratories were also recognized. It was generally assumed also that radioactive materials in sufficient concentration could produce tissue damage on inhalation or ingestion.

3. Radiologists and physicists associated with them in the treatment of cancer with high energy radiation from X-ray units and with radium, as previously pointed out (p. 845), had already worked out protective measures, and fairly reliable instruments were available (*29*). Thus a body of knowledge and protective policy already existed in principle, although it was adapted only to isolated units and rather low levels of operation.

4. Radioactive isotopes (p. 835) were beginning to be used with considerable frequency in many university and other research laboratories for biologic tracer studies (*30, 31*). The amounts used were small, but the materials had to be handled carefully, and decontamination and disposal procedures had to be worked out even for them. Interestingly enough, the compelling need for these safety procedures was not so much the hazard that was beginning to be recognized as it was the local interference with the measurement of isotopes (the so-called background count) if precise techniques of use and disposal were not enforced.

In spite of the realization of the hazards of radioactive materials just described, little formal attention was at first paid to the health and safety aspects of the OSRD program. Uranium was being produced in only small amounts in laboratories and for experimental purposes. Various contractors, it is true, had carried out bulk reduction of ore to oxides, but the amounts of ore they handled were relatively small, and production of uranium oxide was still on a small scale. University research chemists, physicists, and radiologists carried out their research activities as individual groups, and when, occasionally, a physician, usually from the student health department, was questioned informally about the toxicity of these materials, he seldom knew the answer.

Special Precautions

Where the need already existed, the beginnings of a specific, effective health and safety program had already been developed in some laboratories. In Berkeley, Dr. E. O. Lawrence and his group did their principal work on the electromagnetic (cyclotron) separation of U-235 from U-238 in their own laboratory, where the hazards of neutrons, radioactive targets, and materials made in the cyclotron were fully realized. The personnel were well protected by the measures outlined by Dr. J. H. Lawrence and Dr. J. G. Hamilton (p. 845). On the San Francisco campus, Dr. Stone was equally active in protecting his workers. Most of the safety procedures later set up were adaptations and expansions of the elementary radiochemical methods developed by the workers in the cyclotron programs. They were, of course, expanded to almost astronomic proportions in the industrial production of uranium that got underway a few years later.

At any rate, when the uranium program was begun, the principles of safe handling of radioactive materials, although still in their infancy and applied on only a small scale, were ready to build on, and some laboratories already had effective programs.

In the early days of the program, the policy was to avoid all radiation exposure, a desirable goal but one that proved impractical in some situations. It was therefore necessary to set minimal daily dosage standards for various types of radiation, such as gamma rays of various energies, beta rays, alpha emitters, and neutrons.

In January 1942, when Dr. Compton's group at the University of Chicago agreed to concentrate their experimental work on plutonium, plans were already well advanced for developing a uranium pile to produce the chain reaction from which the plutonium was to be derived. The process would be associated with the production of neutrons and radioactive products of fission in amounts never before handled. Moreover, the exceedingly radioactive uranium slugs (biscuits) would have to be extracted chemically for their plutonium content, and thousands of curies of radioactive fission products would be left over in the discarded waste.

At both Oak Ridge and Hanford, the possibility had to be considered that one of these radioactive slugs might rupture in the reaction. Another possibility was that certain radioactive gases would come out in the ventilation process and escape through the chimneys of the piles. A good deal of study was devoted to both problems in both locations by Phil E. Church, Ph. D., who made a complete investigation of the local meteorologic conditions. Although inversions were common in both areas, there was, fortunately, no escape of dangerous amounts of either radioactive or noxious materials that might harm the population.

Eventually, many production procedures were carried out in closed cycles, without human contact. In experimental laboratories, however, where scientific and engineering groups worked in pilot-sized numbers with relatively large amounts of radioactive materials, stringent precautions were always enforced. Until the end of the war there was a constant search for improvement in the chemical separation of plutonium from the mass of fissioned products and unfissioned uranium in solution or in precipitates produced by dissolving the bombarded uranium. Constant supervision was

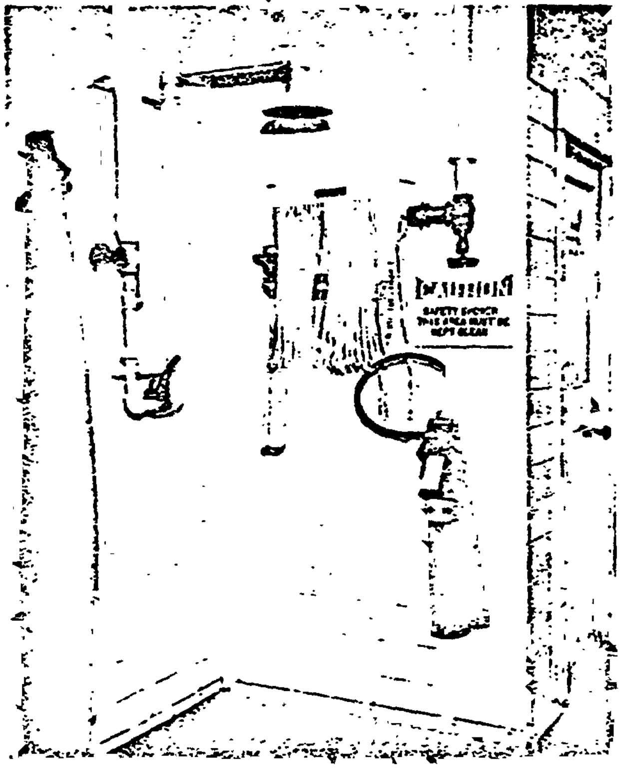


FIGURE 285.—Safety shower at Chicago Metallurgical Laboratory. In areas such as these, personnel whose clothing was accidentally contaminated with radioactive materials could strip quickly and shower thoroughly. Contaminated clothing was handled in a special laundry.

necessary to be sure that the safety precautions laid down were not relaxed at any level of the operation and that no changes were made in it.

Once standards for exposure were agreed on, each industrial process could be analyzed, and the protection necessary could be predicted. The necessary measures varied from personal hygiene (fig. 285) and control of clothing in the so-called changehouses (p. 865) to control of ventilation and of air content. It was not only necessary to protect against total or partial external exposure (hair, nostrils, hands, genitalia). It was also necessary to control exposure from absorbed and internally located radioactive emitters resulting from inhalation, ingestion, and trauma.

If the special construction and other procedures required to protect personnel against radiation and radioactive material could have been reduced or eliminated, it is probable that the atomic bomb could have been produced for considerably less money and in a much shorter time. The shielding and ventilation requirements of uranium and plutonium production and the fabrication of the bomb created enormous structural problems. Radiation and radioactive material from a large variety of sources and in incredibly large amounts were serious controlling and limiting factors during the total process. Remote control and protective personnel measures were necessary wherever radioactive materials and noxious chemicals were handled. Whatever these precautions may have added to the program in terms of time and cost, they were uniformly successful in the protection of the personnel engaged in it.

DEVELOPMENT OF RESEARCH PROGRAM

During the preparations that preceded the entrance of the United States into World War II, as well as early in the war, both the faculties and the administrative personnel of medical schools and allied institutions often found themselves frustrated by the uncertainty of their position in relation to the war effort. Even with a contract from the OSRD Committee on Medical Research, the responsible investigator could not be assured of high priority in research material or of deferment from military service for himself or his associates. It had apparently not yet been realized that time could be saved by increasing the scope and pace of individual research by the grant of more funds to provide more adequate staffing and facilities.

Military hardware factories and other plants manufacturing war materials were given priority ratings for the personnel, equipment, and supplies required by a large military machine. No one seemed to have thought of a similar system of priorities for important areas of biologic and medical research. Even as late as 1943, investigators in these fields had to justify, in competition with soldiers and bullets, their absorption of manpower, equipment, and materials.

It was the policy in the S–1 Section program of the OSRD up to 1943, and thereafter in the Manhattan Project, to set up research and training programs in institutions and departments that had displayed a previous interest in the field of radiation and radiation effects. There were also many programs not directly involving radiation or radioactivity per se, particularly in toxicology, in which special experimental biologic competence was required.

Thanks to its high priorities and ready funds, the Medical Section, Manhattan Engineer District, was able to utilize highly qualified investigators in university groups who either had no research on hand or who had only small OSRD contracts, on which the pace was slow because of inadequacies of manpower and equipment. In such instances, the Medical Section had to exercise diplomacy and discretion in order not to hamper the OSRD project by giving the investigator a new and more urgent assignment, as well as, for security reasons, not to disclose the existence of a competing government group. It was sometimes necessary for the investigator to wait until the fiscal year was up and then not ask for a renewal of his contract.

Occasionally the OSRD grant was supplemented by providing laboratory equipment with which the investigator could wind up his work more promptly. In some instances, the equipment for the MED project was installed before the OSRD project was completed, so that no time would be lost in beginning the work.

The Medical Section personnel were usually able to convince the investigator they wanted that the proposed project was essential to the war effort. Most important, perhaps, was the provision of an adequate budget, usually for the first time in the investigator's experience. With the assumption of the MED project, his time and strength were often taxed to the breaking point, but the work was somehow done, and usually done well.

Data on Effects of Radiation

A considerable body of experimental data was available, upon which further investigation could be built, when the Medical Section, MED, was constituted in August 1943 (*32*). It was not so useful as it might have been because prewar experiments were usually devised with the purpose of creating pathologic lesions by irradiation in order to elucidate organ systems and functions rather than solely to study radiation effects. The available data were derived from work on genetics (*33–36*), on the intestines (*37*, *38*), and on the hemopoietic system. The blood studies were particularly concerned with the life expectancy of the red blood cell and the platelet and their precursors in the bone marrow (*39–41*).

Short-term experiments by Dr. J. G. Hamilton had showed that many very vigorous alpha emitters were also bone-seekers and were likely to damage the human hemopoietic system. Large-scale ingestion and inhalation experiments were regarded as too hazardous and too costly to undertake. They were really unnecessary, since the studies just mentioned had showed that the risk of these emitters was present even in very low concentrations. On the basis of these preprogram studies, handling and ventilating precautions were instituted wherever alpha emitters occurred.

Since many of the heavier metals were used in great quantities with various salts and various valences, Hodge, in 1943–44, ran a rather extensive series of feeding, inhalation, and injection experiments with some of the more commonly used of these metals. He verified that uranium was excreted by the kidneys, with some damage to the glomeruli and tubules. On the basis of this observation, physicians in plants in which uranium salts were handled in large quantities were directed to carry out tests for albumin and phosphatase in the urine, in order to determine, from the pilot survey, how serious this damage was. In the few cases in which renal injury was detected, investigation showed that the workers affected had not observed the specified precautions, which were forthwith tightened up. With these exceptions, all examinations were negative for albumin and phosphatase, and the investigation was discontinued.

The extensive feeding and ingestion experiments carried out by Tannenbaum and Hodge (p. 855) also showed that the kidney that had been damaged was likely to become resistant, the damaged areas healing with no residua of injury. As long as the dosage of uranium was maintained at a low level, albumin and phosphatase would not be excreted in the urine, though the original damage would recur if the dosage was increased.

Development of Instruments

While the development of instruments is not ordinarily classified as research, a most important feature of the control and safety aspects of the Manhattan Engineer District program was the steady improvement in the accuracy and reliability of the instruments used for measurement of radioactivity (fig. 286). Equally important was the reduction in their size and weight. These instruments, to be fully useful, had to be portable, rugged, and capable of maintaining their calibration under extreme conditions of heat, humidity, and transportation. In other words, they had to be both precise and convenient to handle.

The rapid adaptation to biologic experimentation of the Geiger-Müller counter was spectacular. It was used successfully for tracer purposes both experimentally and clinically.

Many institutions before the war built their own counters. Two techniques were widely used, the dry-ash, flat-dish technique and the wet-ash dipping technique. At the University of Rochester, in June 1943, Dr. Bale built a portable, battery-operated Geiger counter, with a probe and 10-inch speaker (*31*). It weighed about 40 pounds and fitted into a large suitcase. It was extremely useful in the industrial inspections that were part of the Medical Section's functions (p. 869).

An extensive study of film badges was made at both the University of Chicago and the University of Rochester, in an attempt to obtain, from the density of the silver deposit on the film, a standard measurement, and also to distinguish the various energies of the neutron-measuring device. Gioacchino Failla, D. Sc., at Columbia, and Dr. Wollan, at Chicago, were among those who devoted a great deal of time to devising a suitable field method for measuring alpha emitters and neutrons.

By early 1945, standards of measurement and calibration had been well worked out. The film badge and the Lauritsen pencil electroscope were standard equipment in all areas in which there was any exposure to radiation, and logs were kept separately for individuals who worked in them.

Others who participated in the development of instruments before and during the war were Dr. Rose, Dr. Morgan, and Dr. Parker, at the University of Chicago, and Malcolm Watts, M.D., at Los Alamos.

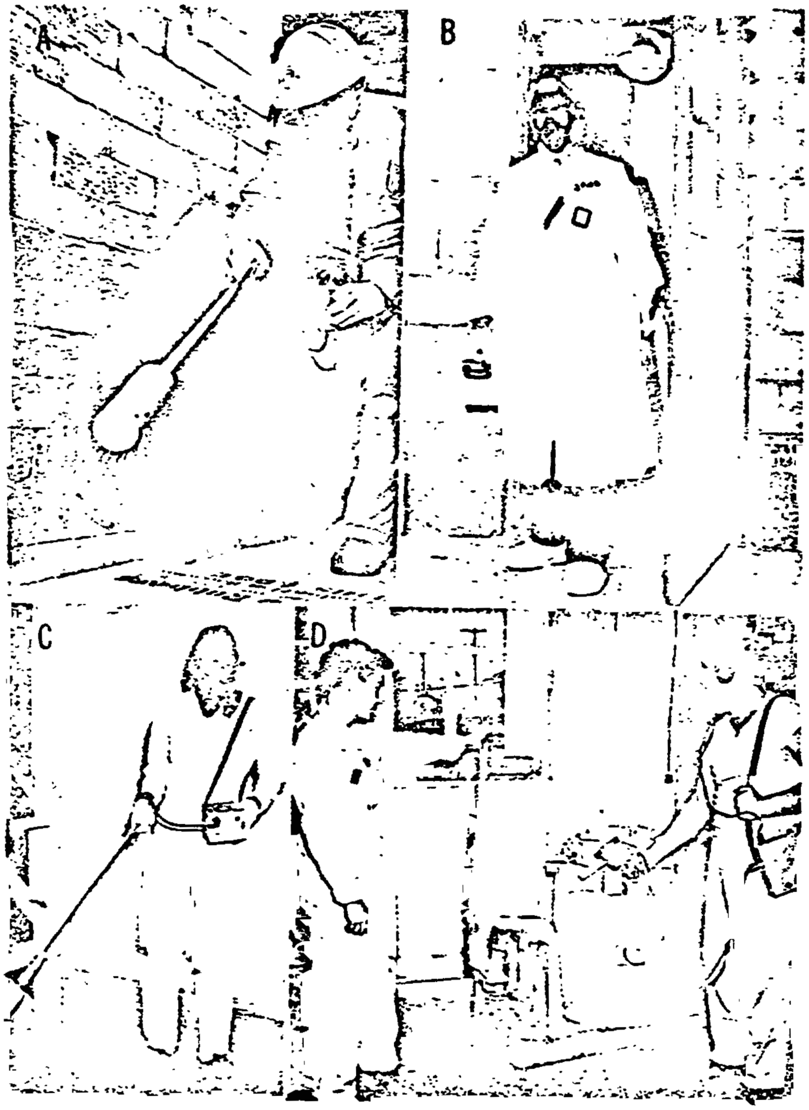


FIGURE 286.—Measuring instruments used to monitor plants and other areas for radiation hazards. Monitors wear protective clothing. A. Long-handled probe. B. Beta-gamma survey instrument carried by worker fully equipped against radiation contamination hazards. Note mask, gloves, canvas bootees, badge, and pencil radiation meter. C. Fish-pole meter. D. Probe counter used to examine container during transportation for radiation leakage. Note washable uniforms, radiation measuring film badges, and pocket pencil-size radiation meters on chest.

DEVELOPMENT OF HEALTH-SAFETY PROGRAMS

University of Chicago Metallurgical Laboratory

Early organization.—In August 1942, Dr. Stone, Professor of Radiology and Chairman of the Department at the University of California School of Medicine in San Francisco, accepted the newly created position of Associate Project Director of Health in the University of Chicago Metallurgical Laboratory (*42*). As soon as he was appointed, he was made a member of the Laboratory and Project Councils, which placed him on a level with the Directors of the Nuclear Physics, Technical, and Chemistry Divisions. He could therefore offer advice on necessary protective measures during the planning stages of the work instead of after health and safety problems had arisen.

Dr. Stone was able to assemble a group of workers at the Met Lab who were capable of dealing with radiation hazards from the planning stage of the problem, as just noted, through the completion and operation of the production piles in Hanford in 1944–45. Sound as was the policy of advance medical planning, it was not a usual one at this time. Because it was initiated by a scientific group of established reputation, this practice became standard policy and was promulgated throughout the pilot and production programs by the Manhattan Engineer District and by all contractors. It can fairly be said that this practice was, in large measure, responsible for the success of the protective measures employed and the greatly reduced risks of an inherently hazardous operation.

By the end of 1942 (that is, by the time the Fermi pile had gone critical), Dr. Stone, with the assistance of Dr. Cantril[5] and others, had coordinated all biologic research for the Laboratory and had developed safety procedures and training exercises which were later applied at the Oak Ridge pilot plant (Clinton Engineer Works) and at Hanford.

The program was operated by three separate groups:

1. A Health Group (Drs. Jacobson and James J. Nickson). This group performed routine physical examinations and made blood counts and urinalyses for all personnel employed in the Met Lab.

2. An Instrument Development Group (Drs. Rose and Wollan). This group designed and calibrated Geiger counters, ion chambers, and electroscopes of various sorts for monitoring purposes and for laboratory use; film badges of various designs; and other instruments for detecting radiation, including alpha particles, beta electrons, and neutrons.

3. A Biological Radiation Effects Group (Dr. Cole and Clifford L. Prosser, Ph. D.). This group endeavored to define the mechanisms of radiation injury, whether from external or internal exposure, in the hope of detect-

[5] Dr. Simeon T. Cantril, a brilliant and well-qualified radiation therapist (*43*), also spent considerable time at the Oak Ridge pilot plant, at the Berkeley Radiation Laboratories, and at Hanford, training personnel. He was also consultant to the School of Fisheries program (p. 878). Later, he went to Seattle, to direct cancer research at the Swedish Hospital, where a million-volt X-ray generator was being installed.

ing incipient or early and minor changes and providing countermeasures which would prevent or heal these injuries. Inhalation and ingestion of radioactive materials were of particular concern (p. 855).

All of these activities were so organized as to enable the Medical-Health Group to keep ahead of design schedules. Because of the time occupied by a single experiment, it was immediately evident that each one could be conducted only once and must be carried out the first time on a large enough scale for results to be significant. The biologic group therefore worked at a rapid pace and used experimental animals in numbers never before contemplated in medical research.

Special protective measures.—The protective measures instituted at the University of Chicago Metallurgical Laboratory were thorough and comprehensive, since, as already stated, those developed for the chain-reacting pile here would be used, in turn, in the pilot plant at Oak Ridge and then in the production piles at Hanford.

The training program set up for contractors' personnel involved testing and perfecting a dry-box technique (fig. 287) for handling materials inside of a box while controlling the operation by vision through a lead glass window; devising suitable clothing, including gloves, shoes, and masks (fig. 288); and development of laundry procedures for cleaning clothing and other materials that had become contaminated. The last of these functions required a search for efficient solvents and so-called complexing materials.

At first, surgical soap and, in extreme cases, aqua regia, were used to cleanse badly contaminated hands. Later, some of the newly devised commercial detergents were substituted and proved most effective.

Since clothing, shoes, and gloves were readily contaminated, so-called changehouses were set up in which clothing worn at work could be exchanged for fresh clothing. The houses were so designed that there was an area of transition from dirty to clean space, and they were amply provided with lockers, showers, and washbasins.

At the beginning of each shift, as the workers reported, clean gowns, jumpers, and coveralls were issued at the entrance of the house. Street clothing was removed and stored in lockers, and the issue clothing was donned. Before the plant proper was entered, canvas boots or galoshes were distributed, and each worker received a mask, a film badge, and a pencil meter (figs. 286B and 286D).

At the end of the shift, the workers returned to the changehouse, where their clothes and boots or galoshes were removed and inspected. Each item was cleaned and measured before it was reissued. The workers then stripped off their coveralls, turned in their masks, and walked, in their clean shoes, to the lockers, where they removed the rest of the clothes they had worn at work and where they washed or showered as necessary. Workers in particularly dusty and contaminated areas were checked with Geiger counters before they were allowed to leave. If special contamination was found on the hands or other parts of the body, official procedures for decontamination were enforced.

FIGURE 287.—Dry-box techniques evolved from wartime methods and designed to protect workers handling small amounts of radioactive materials against radiation hazards. A. Worker at Los Alamos, N. Mex., handling irradiated materials with rubber gloves inside ventilated cabinet. B. Worker at Argonne National Laboratory weighing small amount of radioactive barium in dry box, with his hands protected by rubber gloves against soft beta radiation.

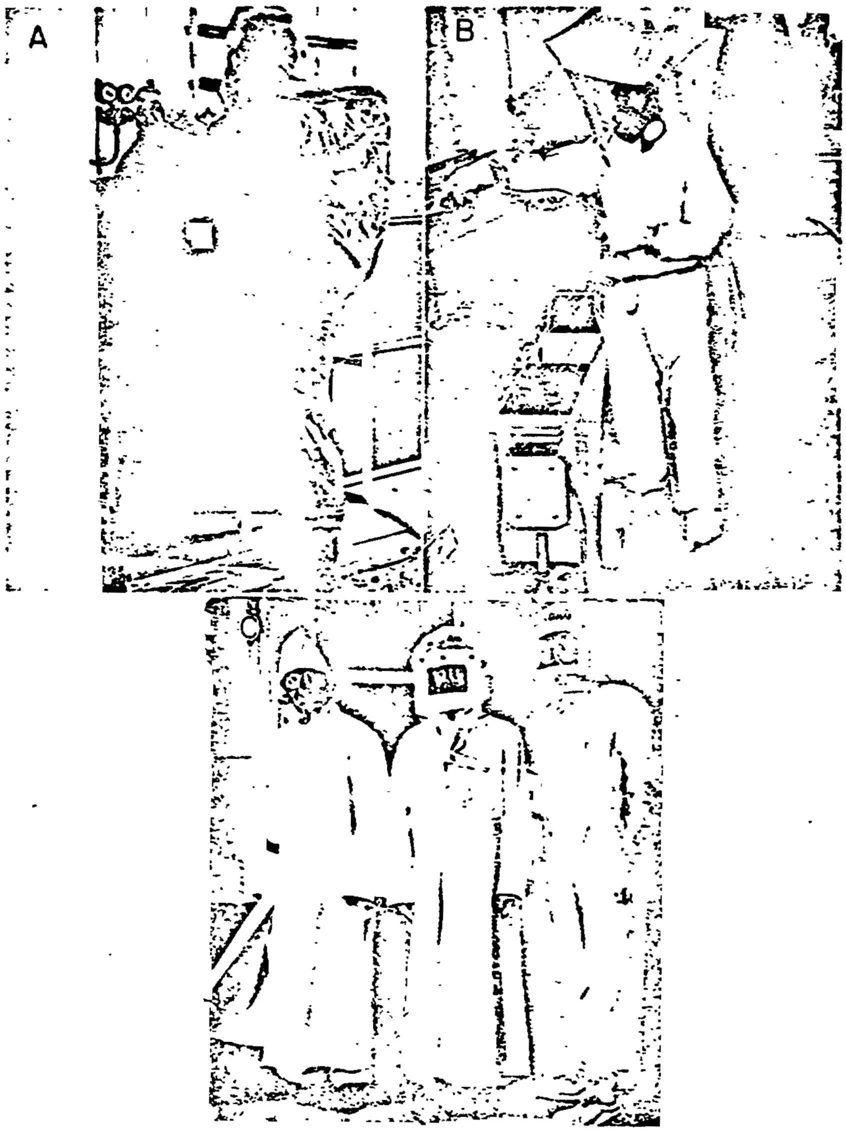


FIGURE 288.—Sophisticated types of clothing evolved from clothing designed during war to protect workers against radiation contamination hazards. A. Suit made entirely of plastic, with seams zipped together to form relatively tight joints. Air from tank on the workman's back is released through nozzle in upper part of the suit to permit him to breathe. B. One-piece vinyl plastic suit, which includes the headpiece, zips up the back. Entrance to suit is through flexible tunnel at back. C. Workers prepared to enter contaminated area. Worker on right wears suit and canvas boots of type used during war. The plastic suit was a postwar development. Worker on left wears cap and mask similar to items used during war.

The workers could not escape the routine just outlined for the exchange of clothing took place just before they punched the timeclocks. Later in the program, when contamination by dust had been controlled, many workers were not required to go through the changehouse procedure.

These measures may seem elementary, but their importance cannot be overestimated. When they were put into effect early in 1944, it was clear that it would be a year or more before structural concrete of the proper thickness, ventilating devices, and other protective features of large piles could be implemented in the construction plans. These requirements had to be given to the engineers well before construction began. In the meantime, the safety of the workers depended upon the elementary precautions just described.

Other University Programs

By the end of 1944, most university pilot research programs had been turned over to industrial organizations. In the meantime, their supervision had proved somewhat more troublesome than that of the industrial field program. Since the chemistry and metallurgy of uranium had previously been of little interest, relatively little work had been done on either subject. When the necessity arose, fairly large pilot programs—almost semiproduction programs—were carried out at a number of universities, chiefly Chicago, Columbia, and Iowa State University, Ames.

With Dr. Stone and his group on guard, the health and safety problems at the Metallurgical Laboratory in Chicago were soon under control (p. 864). At other universities, the serious nature of the risk was not so readily appreciated, and proper precautions were not instituted until the staff physicians of both institutions had been thoroughly indoctrinated and had agreed to accept the responsibility for good housekeeping practices and health and safety supervision of laboratory personnel.

Industrial Field Program

The most complex and most difficult assignment of the Medical Section, MED, was the industrial field program, which ranged from discussions of design with engineers before a plant was built to the safety housekeeping techniques necessary during the processing of ore to metals. Design, construction, and operation of pilot programs were never stabilized at any single stage. They were constantly changing and being scaled upward, to enable the contractor and the personnel of the Manhattan District to obtain data for increased production.

Attention has already been directed to the continuing hazard of the natural production of the strong beta emitters, uranium X1 and X2 (p. 854). The refining process consumed a considerable amount of time, as did the shipping of the material from one place, or even one stage, to another. The hazard was therefore present from the time the ore was received at the docks in New York from the Union Minière in the Belgian Congo, or at Port Hope, in Ontario, Canada, or from the Colorado areas, until it became a slug in a pile. Some lots of the ore were contaminated with radium and therefore gave off radon during storage. The emission of radon was a particular problem with ore from the Congo, and the drums in which it was shipped, and even the freight cars in which the drums traveled, had to be opened with special monitoring and ventilating precautions.

Plant inspections.—The inspection of industrial plants was an important part of the health-safety program (fig. 286). In May 1943, Captain Ferry was assigned to the Medical Section, MED, sent to the University of Chicago Metallurgical Laboratory and the University of Rochester Laboratory for indoctrination, and then assigned to inspection of the industrial uranium processing plants. He was later assisted by Capt. (later Maj.) Joe W. Howland, MC. Both were on the road almost continuously. The scale of operations was so large in Wilmington, Del., where the du Pont Co. was supplying material for the Oak Ridge operation and also tooling up for the Hanford operation that Capt. (later Maj.) Bert T. Brundage, MC, was assigned full time to this location. All medical officers wore civilian clothes on these trips.

With the portable Geiger counter devised by Dr. Bale at the University of Rochester, it was possible to check the situation and, when necessary, demonstrate to the contractor and his foremen that the quality of their housekeeping was sometimes not as good as it should be. The demonstration helped these personnel to enforce among the workers the precautions that would prevent accumulations of uranium X1 and uranium X2 in unwanted places and also, indirectly, prevent losses of scarce uranium salts through spillage and careless handling. The savings in salvaged uranium when undesirable practices were stopped amply repaid the cost of the changes necessary to tighten up the program and carry out the safety and health precautions.

The seemingly crude large-scale extraction procedures employed in the industrial plants were surprisingly effective. Often only simple changes were required to make them relatively clean and dust free. This was fortunate, for there was no previous medical or radiologic industrial experience upon which to draw. The industrial concerns were equally new in the field, and they viewed the arrival of the inspectors with considerable apprehension and at first with open hostility. The inspectors, by frankly admitting that their own ignorance was almost as great as that of the contractors and their personnel, soon established a basis of genuine cooperation.

Plant personnel were told frankly that certain hazards existed but could be prevented; that practices could be instituted which, if sedulously observed, would prevent harm to them; and that the precautions necessary were really quite simple and chiefly based on good housekeeping. The precautions were then listed and described. They included reduction of exposure to toxic materials and radioactive dusts, fumes, and gases; installation of showers and washbasins to improve personal hygiene; use of overalls and masks in some

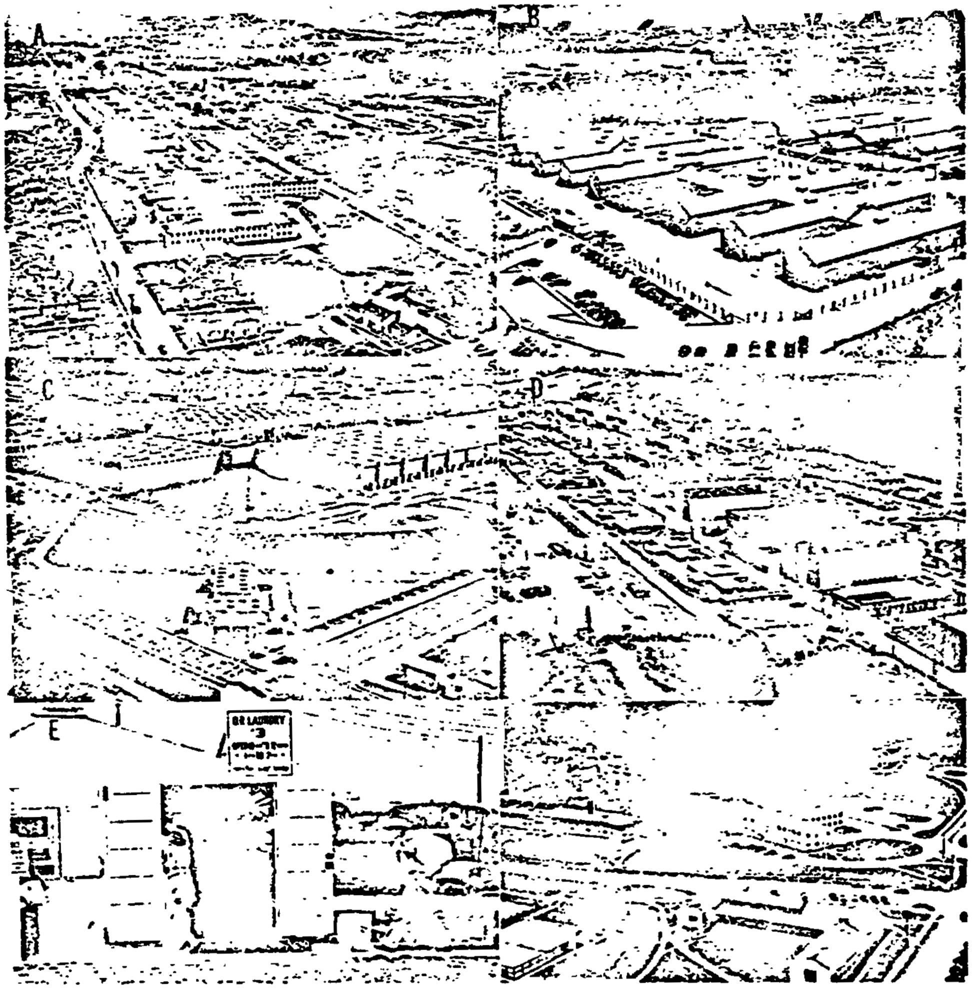


FIGURE 289.—Scenes from Oak Ridge, Tenn. (Clinton Engineer Works), where materials for the first atomic bombs were produced. A. Oak Ridge, at end of war. B. Administration building, containing offices of District Engineer, Col. (later Maj. Gen.) Kenneth D. Nichols, CE. The medical section was also in this building. C. Aerial view of gaseous diffusion plant (K-25). D. Plant (Y-12) for separation of U-235 by electromagnetic process, placed on standby after the war, is shown as modified and altered in 1953. E. Small hutments in outlying sections of city, which provided commercial cleaning, laundry, and other services for civilians. Note trailer camp in background, which housed many workers. F. Guesthouse (center), efficiency apartment building (left), and chapel on hill (rear) constructed immediately after the war.

Industrial program.—The construction companies that built Oak Ridge operated their own first aid facilities and medical care programs for their workers at the construction sites. Men with serious injuries were hospitalized as soon as the Oak Ridge Hospital could receive patients.

When the construction work was finished, the operating companies also set up their own first aid organization, as well as an industrial medical program concerned mainly with safeguarding their workers from radiation and radioactivity hazards. Many of the personnel who were responsible for this program had been trained at the Met Lab in Chicago. They included Dr. Adolph G. Kammer (Carbide and Carbon Chemicals Co.), Dr. James H. Sterner and Dr. Christopher Leggo (Tennessee Eastman Corp.); and Dr. Stone and Dr. John E. Wirth (Monsanto Chemical Co. Clinton Laboratories).

Public Health measures.—The public health problems that promptly became evident at Oak Ridge were put in charge of Lt. (later Capt.) Bernard M. Blum, MC, in March 1944. It was his mission to see that milk was properly pasteurized; that soft drinks were free from insects (a persistent annoyance); that the bacterial counts in swimming pools were at least as low as those in milk; and that sanitary measures of all kinds were observed.

At Oak Ridge, the intake for drinking water was in the Clinch River, downstream from the sewage disposal plant. Both installations were so capably designed that safe, potable water was delivered to the town in ample quantities, a record, incidentally, that has been maintained to this time (1965).

All food handlers were required to undergo physical examinations and to be tested as possible typhoid carriers. All eating places (restaurants and sandwich and soft drink dispensing places) were inspected repeatedly. Flies and mosquitoes were almost eliminated with DDT, in an intensive drive to prevent malaria and poliomyelitis. Great care was taken to trace exservicemen and other workers who might have served, or been employed, in tropical areas. All were tested for latent malaria, but all smears were negative.

The supervisory and preventive public health measures developed at Oak Ridge were instituted in all areas under the control of the Medical Section, Manhattan Engineer District.

Hospital

Planning and construction.—In March 1943, when Dr. Warren made his first visit to Oak Ridge with Major Friedell—before he had accepted the position of civilian consultant to MED (p. 848), and when he still did not know the nature of the project in which he was being asked to serve—the 200 beds suggested for the hospital seemed somewhat excessive for an estimated population of "about 5,000." The inflated size, he was told, was necessary because of the isolation of the area and for "security" reasons. It was therefore decided to plan at first for 150 to 200 beds and to provide for possible increases in size. At the peak of operations, in 1945, the hospital (fig. 290) had 300 beds (*44*).

The surroundings in March 1943 were not promising. The headquarters of the Clinton Engineer Works were set in a sea of mud, which filled all the small valleys between oak-covered hills. Bulldozers were everywhere, and

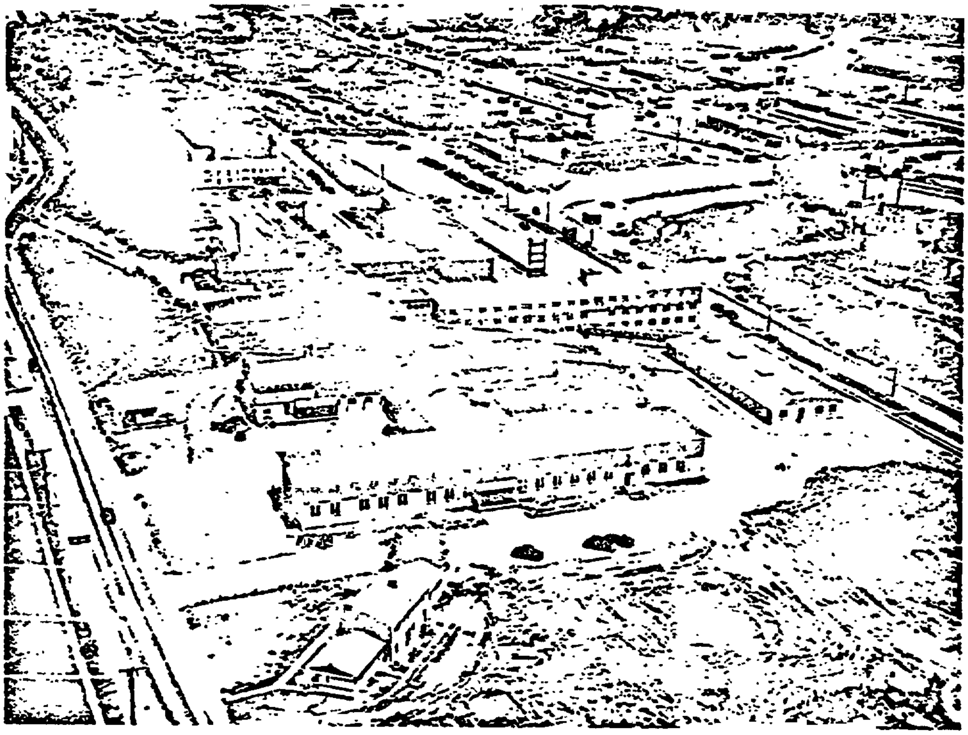


FIGURE 290.—Oak Ridge Hospital and outpatient dispensary.

trucks carrying lumber and other building supplies jammed such roads as there were. The office for the architects who were to design the hospital (Skidmore, Owings & Merrill) was located in a shack set in the center of the other temporary buildings that served as dormitories, cafeteria, and stores. Houses being erected by Stone & Webster were in various stages of construction. The architects' shack was crowded with draftsmen, and it was obvious that other buildings than a hospital were being built.

The discussion on this trip concerned not only the hospital but also other phases of health and medical care for the town of "5,000" people who would work in the plants of this isolated region. At this time, as already noted, the contractors were operating their own medical care facilities. The following month (April 1943), a formal medical care program was set up at Oak Ridge, under the direction of Dr. Rea and Dr. William B. Holt, both of Minneapolis, Minn. The organization of the hospital was part of their responsibility.

Dr. Warren approved the site that had been tentatively selected for the hospital, a small hill at the edge of town (fig. 290). In accordance with what he was told of possible future needs of the population to live within this guarded area, he recommended that the outpatient clinic, X-ray facilities, diagnostic laboratories, and emergency rooms be expanded at once. A dental building was also recommended, on the ground that it would save the workers' time and enhance security if this service were kept on the site.

The hospital was planned and built along modern lines and had standard modern equipment. Construction was begun in April 1943 and the first patients were received on 17 November 1943, when 50 beds became operational. The dental clinic was built the following year.

Personnel.—The Oak Ridge Hospital was operated administratively by the Roane-Anderson Co., and all of its civilian personnel were company employees. At the peak of operations, in August 1945, there were 20 civilian dentists, 141 nurses, 54 nurses' attendants, 8 dietitians, and a total hospital employment of 632, exclusive of 41 medical officers and 1 dental officer. The dental staff, organized by Dr. Harry Pitluck and 1st Lt. (later Capt.) Peter P. Dale, DC, the only Dental Corps officer in the program, was directed for most of the war by Dan Claussen, DDS, later Dean of Meharry Medical College.

Medical officers were provided for the hospital by the Office of The Surgeon General, by the special arrangements already outlined (p. 847). Under this agreement, The Surgeon General was to provide the budget for the [illegible] curred in 1944, in the area outside of the city, from which about 10,000 persons commuted to work in Oak Ridge every day, there were only two suspected cases, both mild, in the city population. The brief indoctrination the medical staff had been given in the recognition of radiation illness was fortunately never put to use.

During the approximately 3 years the hospital operated, 2,810 babies were born in it. There were 344 hospitals deaths. For security reasons, no funerals were conducted within the town, which was classified as an Army reservation, except those of a few former residents who had desired to be buried in their family plots. These funerals had Army escorts.

Insurance Program

A medical and dental insurance program was launched at Oak Ridge early in 1944, patterned after the California Physicians' Service and planned by Dr. Nathan Sinai, Professor of Public Health at the University of Michigan School of Public Health, Ann Arbor, Mich., who was an early pioneer in this field. The dental program proved financially unworkable and was soon abandoned; thereafter, dental service was rendered on a regular fee schedule.

The medical program operated well during the entire war. The charge was $2.50 per month for a single person and $5.00 per month for a family. The program was supervised by a board of trustees, at first appointed by the deputy District engineer from companies working on the site, and later elected by popular vote.

HANFORD, WASH.

There were several reasons why Hanford (fig. 291), was chosen as the site for the atomic energy project known as the Hanford Engineer Works:

1. It was necessary to conduct operations in an area large enough for reactors and population to be separated from each other by a considerable distance, in the event that one of the reactors to be built would blow out or burn up and spread contamination over a large area. Hanford was even more isolated than Oak Ridge.

2. Since Hanford was located in a bend of the Columbia River (map 10), it met the requirement for the large volume of cold, relatively pure water necessary to cool the reactors.

3. Power in the desired quantities could be secured from the hydroelectric plants at the Bonneville or the Grand Coulee Dam.

The reactors at Hanford were designed and built by the du Pont Co. The construction camp, set up in April 1943, at its peak housed 60,000 workers. After three piles were put into operation in the summer of 1944, the population fell to between 4,000 and 5,000 and was composed chiefly of

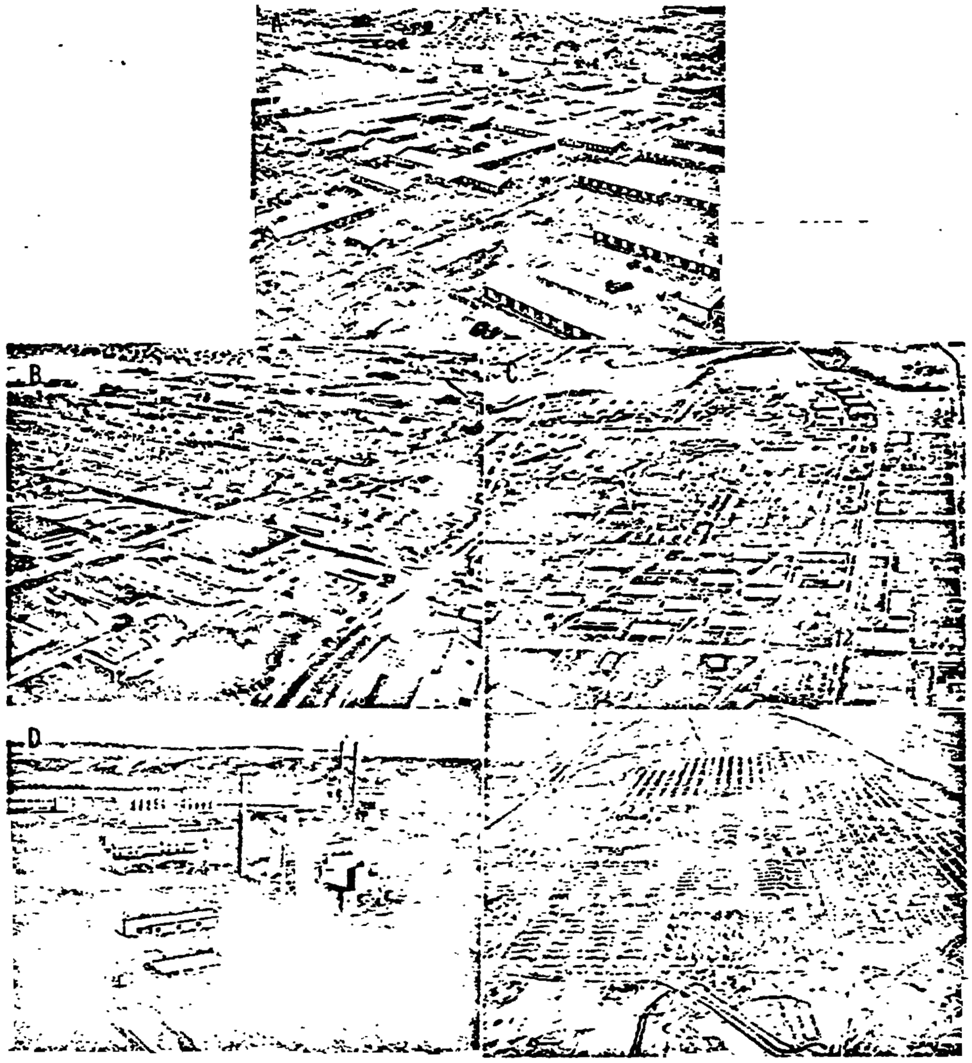
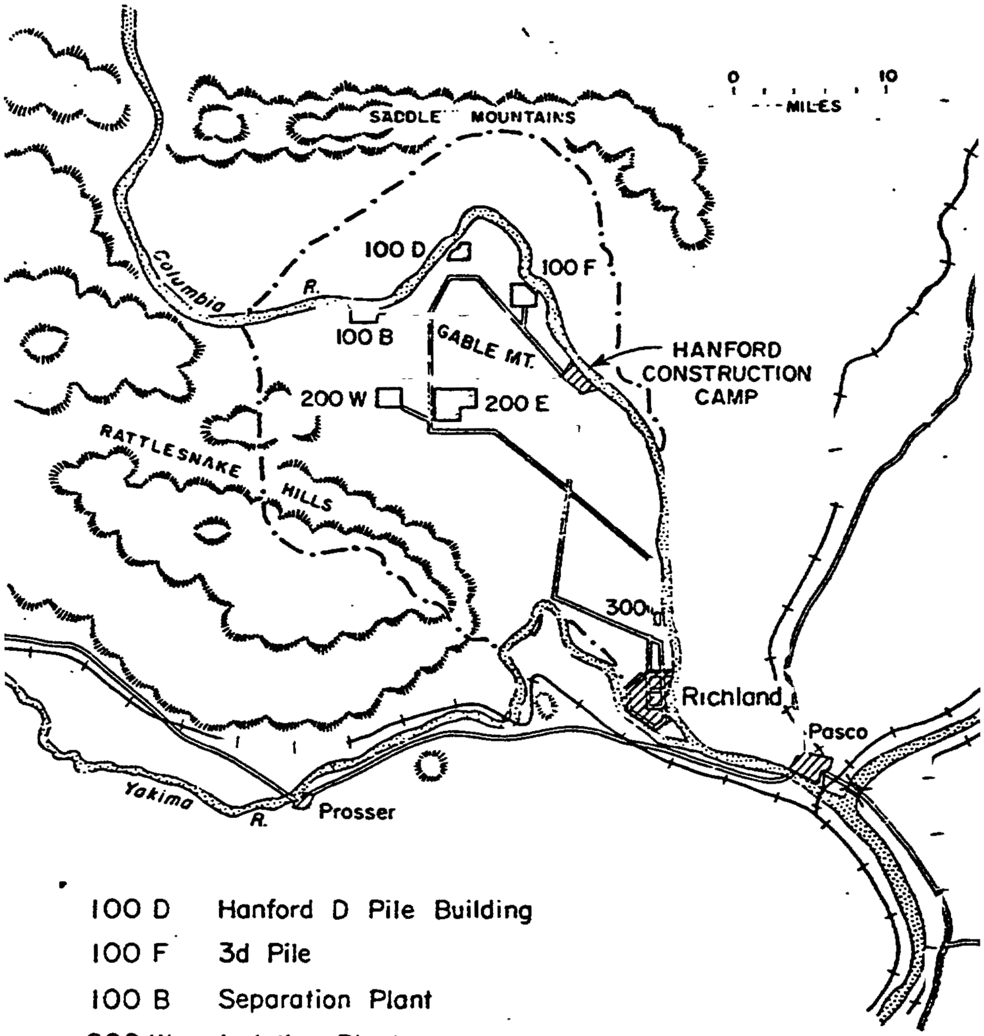


FIGURE 291.—Scenes at Richland, Wash., site of Hanford Engineer Works. A, B, C. Business development and housing, 1945. D. One of war-built reactors, where uranium was transmuted into plutonium. Several buildings in the picture belonged to the waterworks, which used the Columbia River (background) for cooling the reactor at a rate of tens of thousands of gallons per minute. E. Postwar construction camp, with trailer spaces (right, background) and barracks for single workers (center and left).

scientific and production workers. The town was operated under the area engineer, Lt. Col. (later Col.) Franklin T. Matthias, CE.

The Medical Program

Dr. Wm. Daggett Norwood served as medical director for the contractors at Hanford. He had spent considerable time in the University of Chicago



100 D	Hanford D Pile Building
100 F	3d Pile
100 B	Separation Plant
200 W	Isolation Plant
200 E	Plant for Stainless Steel Heat Treatment
300	Uranium Slug Manufacture; Materials Testing

JAS

Map 10.—Site diagram of Hanford Engineer Works on Columbia River, Richland, Wash. Note location of the construction camp housing 60,000 workers during a meningitis outbreak which could have brought the work on the atomic bomb to an abrupt halt if it had reached epidemic proportions.

Metallurgical Laboratory with Dr. Stone's group, and he had a full understanding of the industrial hazards of the Hanford operation. He was able to obtain the services of Dr. Parker, who had also trained with Dr. Stone's group and who became local health physicist in the operating plants at Hanford.

Dr. Norwood supervised the design and construction of the Kadlec Hospital, located in what is now the town of Richland, Wash., which served the Hanford population. Construction was begun in late 1943 and the hospital was completed the following spring. Its full-time staff was entirely civilian.

The health and medical operation at Hanford was extremely efficient. While 40,000 construction workers were still employed there, a number of cases of meningitis occurred. There were two deaths, but the disease did not spread and its occurrence was brief. If it had reached even mild epidemic proportions, the construction program would probably have ground to a halt, for there was an extremely limited supply of physicians and nurses in the area, the medical program was not yet fully organized, and the local hospital was not yet far enough along in construction to have handled even a mild epidemic.

Protection of the Columbia River.—The public health and other problems at Hanford were much the same as at Oak Ridge and were handled in essentially the same way. There was one special problem, however—protection of the Columbia River and its biologic contents from contamination and other effects of the production of atomic material for the bomb. Outgoing cooling water would flow into the river, and the possible changes in its temperature might have an adverse effect on both local and migrating fish. A chemical effluent from the cooling water purification process might also be harmful. Since it would be practically impossible to produce distilled water during the final refining process, the water that flowed back into the river would contain a little sodium, potassium, silver, and other elements that might have been made radioactive by neutrons as they passed through the piles.

Dr. Cantril, who had been brought into the Chicago group as a consultant very early in the operation (p. 864), was transferred to Hanford and assigned the problem of protecting the Columbia River and its inhabitants. He promptly secured the assistance of Professor Donaldson, of the School of Fisheries, University of Washington, at Seattle. Through direct observations and local experimentation, it was found possible to return the cooling water to the river at such a point in the bank, and in such a direction, that it offered no thermal barrier to migrating fish.

The water of the river was snow water and therefore almost pure to start with. The very small amounts of minerals left in it, however, after it had been purified were made radioactive while they were passing through the pile, where they were subjected to neutron bombardment. Even though the radioactivity was short lived, it was considered necessary, in order to prevent appreciable concentrations of these radioactive materials, to keep the water in holdup ponds and to restrict the rate at which it flowed back to the river. The essential point of the method was to increase the length of the path, and therefore the length of the time, of the return flow of the cooling water.

Constant monitoring devices were installed in the effluent, and small fish were kept in tanks fed by suitable baffles from effluent waters to act as controls on the temperature and radioactive materials in the water.

LOS ALAMOS, N. MEX.

Organization and Operation

Los Alamos, N. Mex. (map 11), the site of the laboratory in which the first atomic bomb was constructed was established as a regular military post.

The first commanding officer was Lt. Col. (later Col.) John M. Harman, CE. In May 1943, he was succeeded by Lt. Col. Whitney Ashbridge, CE, and was followed in October 1944 by Col. George R. Tyler, CE, who served in that capacity until November 1945.

The Area Engineer's Office for Los Alamos was located in Sante Fe, N. Mex.

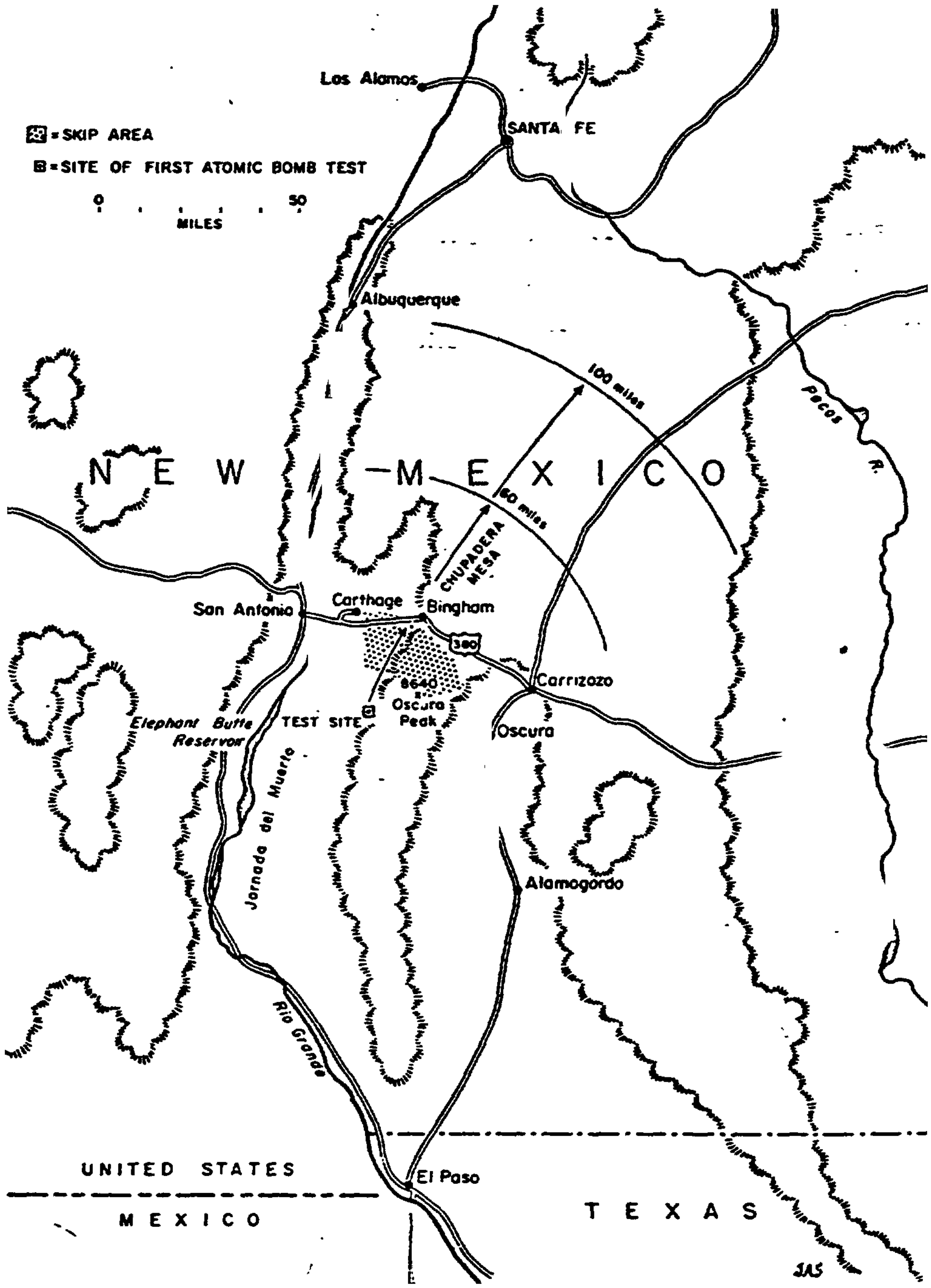
The scientific program of Los Alamos was directed by J. Robert Oppenheimer, Ph. D. The University of California served as the scientific contractor.

The medical program was under the direction of Capt. (later Lt. Col.) James Nolan, MC, whose staff of medical officers was procured through the Office of The Surgeon General (p. 847). Most of them came from St. Louis, Mo., and its environs. Health and safety precautions in the laboratories and industrial plants were the responsibility of Dr. Hempelmann. A resident veterinarian, Capt. J. Stevenson, VC, cared for the war dogs used in the peripheral guard areas and vaccinated all privately owned dogs of the resident population against rabies.

The population of Los Alamos did not rise above 5,000 at any time and was sometimes as small as 3,000. The local hospital was therefore always small, usually between 16 and 20 beds. Obstetrics and pediatrics were the busiest specialties. Hospital service was supplemented by a fairly active outpatient clinic and a small dental unit. The excellent care given by Captain Nolan and his staff to this isolated population contributed greatly to their morale and to the stability of this highly critical program.

Research Problems

Radioactivity during production of the bomb.—The problems at Los Alamos during the large-scale fabrication of the plutonium, U-235, and beryl-



Map 11.—Area of first atomic bomb test: Los Alamos, where final preparations were made, and Alamogordo test area in the desert, where the bomb was detonated. Note skip area about 15 miles wide 10 miles from site of detonation.

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lium required for manufacture of the atomic bomb were of the housekeeping variety already described. The safety precautions, which were the same as those employed at Oak Ridge and the Met Lab at Chicago, covered ventilation, decontamination, personal hygiene, and disposal of wastes.

Research problems that originated from the wide variety of experiments constantly underway with radioactive materials at Los Alamos covered beryllium dusts, nitrite effects from handling of explosives, fumes from high explosives, and solvents seldom or never previously used. Some of these experiments, which involved the use of explosive mixtures and rather wide dissemination of radioactive material, were carried out in deep canyons, so that contamination was limited to inaccessible areas of wilderness.

Laboratory space for research not absolutely essential to the fabrication of the bomb was limited, but some biologic studies were carried out on the effects of radiation and on the metabolic pathways of certain radioactive metals, chiefly plutonium and beryllium, by Wright H. Langham, Ph. D. Dr. Hempelmann, with the assistance of Dr. (later Captain, MC) Harry D. Whipple, investigated the absorption of plutonium and other metals through traumatic wounds sustained by shop workers.

Effects of the Atomic Bomb

The chief effort at Los Alamos was devoted to the design and fabrication of a successful atomic bomb. Scientists and engineers engaged in this effort were, understandably, so immersed in their own problems that it was difficult to persuade any of them even to speculate on what the after effects of the detonation might be. Their concern was whether any one of their several designs for the bomb would actually detonate, and, if the detonation did occur, how massive it would be.

Little attention was therefore paid to the possible effects of the detonation of the bomb until the spring of 1945, when the Medical Section of the Manhattan Engineer District raised the question with General Groves and was given the mission to investigate the whole matter. Two effects had to be studied, (1) blast and (2) fission product radioactivity. There was little time to spare. By May, the tower for the blast and the accessory apparatus were being erected on the flat desert at Alamogordo, 183 miles from Los Alamos (map 11), and it was apparent that the test would occur within the next several weeks.

Blast effects.—Attention was first devoted to blast effects of the bomb. A detonation on the order of several thousand tons of TNT would undoubtedly have massive effects, beginning with the formation of a lethal blast wave front.

The literature contained little on the subject except the U.S. Army Ordnance tests on goats, which had been carried out with small high explosive charges. Available data showed that lethal effects were produced by relatively high pressures, in the neighborhood of 15 psi (pounds per square inch). Certain British studies showed that the terrain and the objects of various sizes in the path of the concussion wave produced complex reflections, skips, and concentrations. Jackets and other heavy clothing offered a degree of protection, but how much could not be determined because of lack of precise measuring devices. Debris carried by a blast wave at high velocity acted as missiles, which were often more damaging than the wave itself.

Circumstances at Los Alamos were not favorable for controlled experiments, and time did not permit them. The best that could be done was to verify the lethal effects of high explosives by hanging rats and mice on wires suspended several feet above the ground at varying distances from charges which were also placed several feet above ground. Dr. Hempelmann and Captain Nolan, who conducted these studies, found that the critical pressures covered a wide range; they began at 5 psi but were more constant at 15 psi. Part of the discrepancy was explained by irregularities of wind and terrain, and by the crude measuring devices used. Further experiments on a flat desert area with a very large chemical detonation showed that mice hung on wires 6 feet above ground would be killed by a blast wave at distances of a thousand feet and more.

Autopsy on these animals rather uniformly showed their lungs to be full of plasmalike fluid. Small hemorrhages and hemorrhagic markings were observed on the pleura, and large abdominal vessels were sometimes ruptured. If the injury did not produce these extreme effects, recovery without lasting sequelae was fairly prompt.

Radioactive effects.—The radioactive effects of the detonation of the first atomic bomb were entirely speculative. When the Medical Section, MED, asked the authorities at Los Alamos for help in this task, an advisory committee was appointed, consisting of Captain Nolan, Dr. Hempelmann, Paul C. Aebersold, Ph. D., and Joseph O. Hirschfelder, Ph. D.

It was estimated that during the detonation of the bomb, about a million curies of radioactive fission material might be released. These products—all as yet unknown—would presumably be in element form, but they would immediately become oxides and perhaps then would agglomerate with vaporized moisture and debris. It was also thought that these materials would rise very high in the large, hot, ascending cloud expected after the detonation, and that, while they were falling back to earth, they might be carried by the wind for considerable distances, perhaps even far from the test site.

Preparations for the Detonation

Over a 3-month period in the spring of 1945, Colonel Warren made an intensive study of cloud and wind situations over the entire southwestern United States. The physical geography of the country around Los Alamos was also studied, with special attention to areas of cultivation and population. The facts of the explosion in 1883 of the volcano Krakatau in Sunda Strait between Java and Sumatra, the largest such explosion of modern times, and of a number of large military detonations were reviewed in detail, in an attempt to obtain some indication of what might be expected to occur after a detonation of the magnitude anticipated for the atomic bomb.

Alamogordo, N. Mex. (map 11), was selected for the site of the detonation after careful study of the adjacent terrain. Along the main east-west highway (380), between Socorro and Carrizozo, N. Mex., is the ghost town of Carthage, and a little further (about 10 miles) east is Bingham, consisting of a crossroads store and a windmill. The area, 40 miles square, selected for the test site had this highway as its northern boundary, with the Carthage turnoff as about its middle point. The site, which was part of the White Sands and Alamogordo Bombing Range, consisted of slightly rolling gravel desert, with little grazing potential. It extended roughly from the Sierra Oscura Cliffs on the east to the Elephant Butte Reservoir on the Rio Grande on the west and was a part of the Jornada del Muerto Desert. It is a place of great heat and drought, interspersed with violent winds and thunderstorms.

The sites for the detonation and the base camp were separated from each other by about 9 miles. The base camp served as scientific headquarters for the group preparing for the test. Bunkers and other paraphernalia were distributed about the area as necessary.

Since it was essential that the test of the bomb should be carried out in good weather, without risk of the frequent thunderstorms that occurred near Alamogordo, a meteorologist, Mr. Jack M. Hubbard, was attached to the Los Alamos Staff, and Col. Joseph Hostrum, AAF, from the Air Force Meteorological Service, was later assigned as consultant. Their studies showed that what was now coming to be called fallout might, under certain weather conditions, become a serious hazard.

A careful study of optimum test conditions was therefore undertaken. The area surrounding Alamogordo was investigated in all directions by air, on foot, on horseback, and in cars, to locate the smallest concentration of population. It was decided that the test shot should be made only when the winds at high elevations were in the northeast direction. In these circumstances, if there was a large amount of radioactive fallout, it would occur in an almost uninhabited area extending about 100 miles northeast of the test site. The wind on the day appointed for the test would thus be an extremely important consideration.

A field program was organized for local and distant monitoring, to safeguard the regional population. For distant areas, monitors were furnished with cars and measuring equipment and had radio communication with the base camp.

General Groves had been authorized to declare martial law if necessary. He had made secret arrangements with the Governor of New Mexico for procedure in the event of a catastrophe. Preparations were made to halt all air traffic between Albuquerque, N. Mex., and El Paso, Tex. (map 11), the day of the test. All personnel not absolutely needed were evacuated from the test site. When the detonation occurred, all personnel would be at least 8 miles away in bunkers or at least 9 miles away at the base camp. Those in the base camp were directed to lie prone, with their feet toward the test tower. Dark glasses of density two or welders' goggles were to be worn by all personnel in bunkers and at the base camp. The bus loads of high officials who would witness the test were located on some low hills 20 miles northwest of the test site.

Since all personnel not needed had been evacuated from the test site, sufficient medical facilities were available at the base camp for any emergencies that might arise. Three medical officers were brought down from Los Alamos, also for possible emergencies.

No therapeutic measures had been devised, and the measures listed were the only protective provisions set up against the effects of the blast. Speculations as to what they might be were rampant, but were of little help in preparing for possible eventualities.

ALAMOGORDO, N. MEX.

Detonation

The test of the atomic bomb was set for 15 July 1945 but was postponed for 24 hours because of unsuitable weather. The postponement raised to an even higher pitch the fatigue and tension in personnel at the base camp.

The bomb was fired at 0600 hours the following morning, 16 July, at a time when, Mr. Hubbard predicted, there would be a lull in, or a general collapse of, the wind pattern, followed by a general movement of winds to the northeast above 20,000 feet. His predictions were entirely correct.

The details of the detonation of the first atomic bomb are well known and need not be repeated here. The blast wave, as expected, produced an abrupt push, and, almost at once, a great creamy white cloud, tinged with magenta, formed and within 15 minutes rose to a height of about 70,000 feet. It then spread out in a mushroom effect, about 8 to 10 miles in diameter, and towered at this height, leaning slightly north and northwest, for more than 3 hours.

For a few seconds after the detonation, the light and heat were intense at the base camp 9 miles from the test site. During the first few minutes of cloud formation, large objects could be seen skyrocketing down from its lower third. About 3½ hours after the blast, the column could be seen to break up at different levels with the wind shear (a sharp discontinuity caused by two contiguous streams of air flowing in different directions). Small portions went in different directions at different levels, some to the west and southwest, and a few to the north. The main portion of the cloud, however, particularly the part composing the mushroom above the 40,000- to 70,000-foot level moved, as predicted, to the northeast.

Fallout

By noon, 6 hours after the bomb had been detonated, the team appointed to survey its effect had identified a heavy fallout in a roughly oval area, extending about 10 miles north-northeast and including a slightly depressed crater covered with what seemed to be greenish glass. Fortunately, the fallout did not block any roads, especially the important east-west highway between Socorro and Carrizozo.

A few days later, fallout was found in some canyons north of this highway, about 30 miles away from the area of the crater. Some was also found at the base of the Chupadera Mesa, but the high cliffs and lack of roads prevented further exploration at this time, in addition to the fact that preparations had to be made for the departure of the survey team that had been ordered to leave for Japan on 13 August, to study the effects of the bombs that had been dropped on Hiroshima and Nagasaki.

When these observations were made, it was concluded, because the cloud and column had remained standing so long over the area in which the crater had formed, that most of the fallout had come down on the test site. It was not until almost a year later, when white-backed cattle were brought in from the uninhabited upper stretches of the Chupadera Mesa, that it was realized that fallout from 60 to 100 miles from the test site had been significant. The skip of 20 to 30 miles that occurred in the fallout pattern, about 20 to 30 miles from point zero, has been found, in subsequent U.S. tests, to be rather common. Apparently it is brought about by the choice of slow winds for the test period, with the aim of keeping the greater part of the fallout on the test site. The failure to detect his skip in the first test gave the false impression that the fallout had been restricted to the test area and also produced the impression that it was less dangerous than subsequent investigations proved it to be.

A much more detailed survey, made 5 years after the detonation of the bomb at Alamogordo by a team from the University of California at Los Angeles, showed that the fallout in the mountainous desert was much more widespread than had been suspected when the observations just described were made. Fortunately, intense radioactivity was never found at a significant biologic level in any cultivated or inhabited area surveyed. The potential hazard during wartime conditions was, however, very clear, even at this early date, to those who had participated in the investigation from the time the first bomb was tested.

JAPAN

Preparations for Dropping the Bomb

In anticipation of a successful outcome of the test detonation at Alamogordo, the atomic bombs fabricated at Los Alamos from material supplied by Oak Ridge and Hanford to drop on Japan had been dispatched to Tinian in July on the U.S.S. *Indianapolis*. Captain Nolan went with them, to enforce safety precautions during their transportation from the United States and the loading of the planes on Tinian, which would be the takeoff point for the bombing of Japan.

Meantime, the Medical Section, MED, had been asked by the Air Force to investigate possible hazards to the crews of the planes that would drop the bombs on Japan. It was agreed that there were three chief hazards.

1. It was at first feared that the bright light of the blast might blind the pilot, so that he could not function. It was concluded, however, that the plane would be too far away from the site of the detonation for the intense light to affect him if simple precautions were taken.

2. The effects of heat and of gamma and neutron radiation were also feared at first, but they also were eliminated because of the factor of distance of the plane from the site of the drop.

3. Blast pressure was a more serious threat. It was known that a static pressure of 0.5 psi could break the wings off a plane and severely damage its flaps, but the situation in flight was dynamic, not static, and varied from minute to minute. No criteria existed to serve as guidelines. It was finally concluded that since the plane would be under emergency (that is, full) power after release of the bomb and, since it would be going in the same direction as the advancing blast wave, it would gain so much speed and distance that it would present the smallest possible surface to the advancing wave and thus would sustain the least possible damage in the conditions to be encountered. If information on static pressure could be taken as a guide, the estimated pressure per square inch at the time when the blast wave caught up with the plane would approach the danger level, but this was a chance that would have to be taken.

As events happened, the planes that dropped the bombs on Hiroshima and Nagasaki experienced severe, but not serious, bumps, and, because of their distance from the detonation, were not exposed to radiation.

Survey Team

An atomic bomb was dropped on Hiroshima on 6 August 1945, at 0815 hours. Seventy-six hours later, at noon on 9 August, a second bomb was dropped on Nagasaki.

On 11 August 1945, Colonel Warren received orders by phone from General Groves to organize a survey team to proceed by air to Guam, on the way to Japan, under special War Department orders (fig. 292), with three missions:

1. To take measures to insure the safety of troops that would occupy these atomic-bombed cities.

2. To investigate radioactivity on the ground and, if it were present, to record the amounts.

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"DECLASSIFIED – DOD Directive No. 5200.9, 27 September 1958" 7/8/60

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LT COL HYMER L FRIEDELL ZERO THREE FOUR TWO FIVE SEVEN EIGHT MC

CAPT HARRY L BARNETT ZERO FIVE TWO FIVE ONE TWO MC

CAPT PAUL O HAGEMAN ZERO FIVE FOUR ONE EIGHT SEVEN THREE MC

CAPT ROLAND VARLEY ZERO THREE THREE EIGHT FIVE TWO TWO CE

CAPT HARRY O WHIPPLE ZERO FIVE SEVENTEEN TEN FIVE MC

CAPT WALTER C YOUNGS JR ZERO TWO FOUR SIX FOUR NINE FIVE MC

1ST LT JESSE H ALLEN JR ZERO SEVENTEEN THREE SEVEN NINE FOUR MC

FIRST LT B M BRUNDAGE ZERO FOUR FOUR SEVEN NINE TWO TWO MC

FIRST LT DONALD L COLLINS ZERO ONE ELEVEN THREE ONE FOUR EIGHT CE

FIRST LT GEOFFREY E CORING ZERO FOUR SIX EIGHT FOUR ONE TWO CE

FIRST LT JOE W HOWLAND ZERO FIVE FIVE SEVEN EIGHT TWO FIVE MC

FIRST LT RICHARD A TYBOUT ZERO FIVE TWO FOUR NINE TWO ONE CE

FIRST LT BERNARD S WOLF ZERO FIVE FOUR FIVE NINE SEVENTEEN MC

FIRST TECH SERV DET MISC WD GROUP WITH STATION SAN FRANCISCO CALIF

BY ORDER WARSEC WILL PROCEED BY SPECIAL PLANE FROM HAMILTON FIELD CALIF TO

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A TRUE COPY:

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WILLIAM L. UANNA
Major, M.I.S.

FIGURE 292.—Orders from Secretary of War creating the first technical service detachment ordered to Guam, to undertake a special mission for the Chief of Staff. These orders procured support and transportation into bomb-shattered Hiroshima and Nagasaki, Japan, before they were entered by military forces.

3. To report on the amount of blast and other damage caused by the bomb.

If Japan did not surrender unconditionally, the personnel of the survey team would be used as the nucleus of a tactical force to support the III and V Amphibious Corps in the later assault on that country. On the preceding day (10 August), however, the Japanese had agreed to accept the Potsdam ultimatum, though with certain reservations. The team left San Francisco on 14 August, though the formal terms of surrender were not signed until 2 September.

As soon as General Groves' orders to Colonel Warren were received, production plants and research laboratories were stripped of their portable Geiger counters, and enough ion chamber instruments, calibrating sources, and batteries were accumulated for a 2-month operation, since it was considered unlikely that any instruments or other supplies could reach the team later in time to be useful to it.

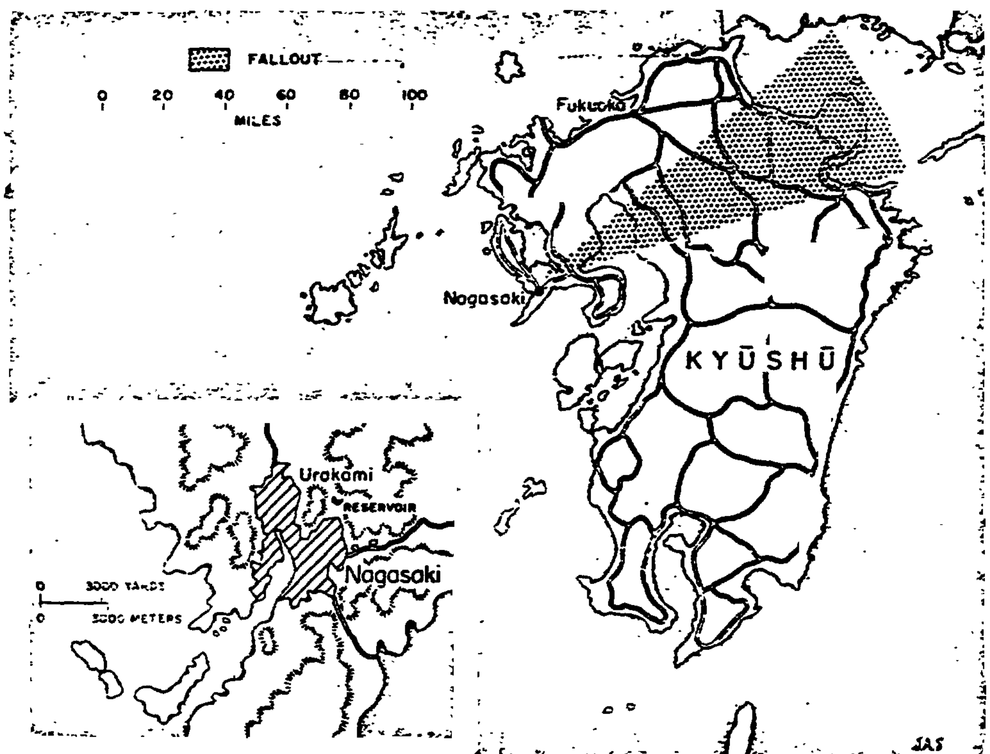
Colonel Warren, Colonel Friedell, and the other officers and enlisted technicians who constituted the survey team arrived at Tinian on 17 August. Here the group was split. Half went with Colonel Friedell to Zamboanga, Mindanao, with the III Amphibious Corps and, after many frustrating delays, reached Hiroshima on 26 September. They returned to Tokyo by train on 11 October.

The other half of the team went with Colonel Warren via Guam to Okinawa, to join the V Amphibious Corps. By this time, as just pointed out, all fighting in the Pacific had ended.

On 8 September 1945, Colonel Warren arrived in Hiroshima by air from Tokyo, in a party consisting also of Brig. Gen. (later Maj. Gen.) Thomas F. Farrell, CE, of the Manhattan Engineer District; Brig. Gen. James B. Newman, Jr.; Capt. James Nolan; Col. Peer de Silva; Col. Ashley W. Oughterson, MC, Consultant in Surgery, Headquarters, USAFWESPAC; Dr. Junod, of the Swiss Red Cross; and two Japanese medical officers, Adm. Masao Tsuzuki (*45*) and Maj. Matao Motohashi, who were to serve as interpreters. This party returned to Tokyo by train on 14 September, and 5 days later, with their technicians and equipment, they flew to Nagasaki (map 12), where they remained until 8 October (fig. 293).

Both Colonel Warren's and Colonel Friedell's groups left Japan by air on 12 October, in the Manhattan District plane *Green Hornet*, just ahead of the typhoons which struck those islands and Okinawa a few days later. The party reached the United States on 15 October 1945. The officers of the Medical Section at once prepared reports of their survey (figs. 294 and 295).

Japanese physicians and scientists were extremely helpful during the survey, and the general population, including those injured by the bomb, acted as patients act everywhere. There were no incidents, even though the survey party were in the bomb-shattered cities and elsewhere in Japan before the country was occupied by U.S. troops.



Map 12.—Nagasaki, Kyushu, Japan, where second atomic bomb was dropped for military purposes. Note area of fallout.

It was the consensus of the U.S survey team and of all the Japanese with whom its members came into contact that a coastal assault on Japan could not have been made without tremendous losses of ships and men, including U.S. casualties of perhaps 500,000, two to four times as many Japanese casualties, and complete destruction of Japan. The use of the atomic bomb, some observers held, gave the Japanese Government the opportunity to surrender without loss of face or need to commit hara-kiri. Fewer were killed by the bomb than had died in the Tokyo-Yokohama raids with conventional bombs. The ethics of the use of the atomic bomb had been raised by U.S. newspapermen in Tokyo, but many Japanese told the survey team they could not understand why the question should have been raised at all: Their own forces would have used it without the slightest qualm if they had had it themselves.

It is realized that this information was not the concern of the survey team, but the discussion came up when fixed coastal gun installations and Kamikaze stations were visited in the downwind area, and it is included for record.

FIGURE 293.—Survey team in driveway of tuberculosis hospital just before departure from Nagasaki in October 1945. Col. Stafford L. Warren, MC, chief of team, is holding doll and case given to the team by the Japanese medical commandant of this unit.

Radioactivity and Blast Damage

In spite of primitive transportation conditions and almost continuous rain, the instruments brought with them by the members of the survey team functioned satisfactorily and lasted well enough to permit an extensive survey of the detonation area in Nagasaki (map 13) and a somewhat less complete survey of the Hiroshima area, where team activities were hampered by lack of roads in the down (northwest) wind areas.

In all the areas examined, ground contamination with radioactive materials was found to be below the hazardous limit; when the readings were extrapolated back to zero hour, the levels were not considered to be of great significance. The explanation was that the detonation occurred at about 1,800 ft., and the fireball therefore did not actually touch the ground. Vaporized materials arose from the ground in the updraft and mixed with fissioned materials, but at that, the amount of radioactive contamination was lower than had been expected.

In Nagasaki, where the affected area was examined more thoroughly than in Hiroshima, the approximate center of the detonation (figs. 296 and 297) was indicated by a uniform charring of the top and sides of a single fencepost. Other posts in the same area (fig. 298) were more charred on one side

FIGURE 294.—Analyzing observations made in Hiroshima and Nagasaki, in office of Medical Section, Oak Ridge, Tenn., November 1945. A. Lt. Col. Hymer Friedell, MC, Col. Stafford L. Warren, MC, Capt. Charles Varley, CE, and Maj. James Young, CE, all members of the party that went to Japan immediately after the first atomic bombs were dropped. Note Atomic Bomb patch, which soon afterward became the official designation for military personnel of the Manhattan Project and Manhattan Engineer District. B. Lt. Col. Friedell trying out some Japanese medical record translation on Major Young, who is not convinced.

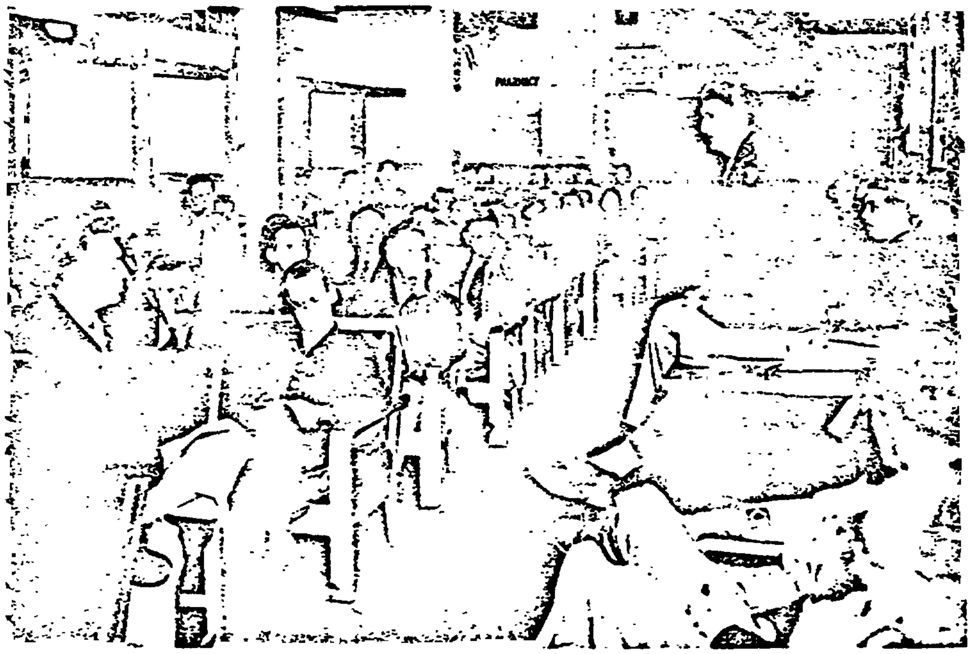


FIGURE 295.—Scene in outpatient clinic, Oak Ridge Hospital, 1 November 1945, with Col. Stafford L. Warren, MC (seated on table), reporting to hospital staff on survey of Hiroshima and Nagasaki. Listeners were medical officers of hospital staff, medical men from plants, a few dentists, and several nurses.

than on others. Trees, walls, and other standing objects leaned outward spokewise from this central point. The effect was particularly notable to the northeast, up the low hill on which the prison was located.

Induced radioactivity from neutron bombardment could be demonstrated in sulfur insulators, copper wires, and brass objects, in human and animal bones, and in the silver amalgam in human teeth, for a distance of about a thousand meters from the assumed mid point of the destroyed area. The neutron effects ceased rather sharply. It is unfortunate that it was not possible to make precise enough measurements to determine the full extent of the affected area.

The wind at the time of the Nagasaki detonation carried the debris to the east. It could be traced along the roads to the ocean for 90 to 100 miles in a path at least 40 miles wide at the seashore.

Nagasaki lies in the Urakami Valley, which is generally narrow but is about 2,500 meters wide at the detonation point. The eastern wall of the valley rises almost 2,000 feet above the valley floor. The hills were covered by terraces and rocks, and there were almost no dwellings to be damaged. In the next valley, however, the fallout path crossed the north end of the reservoir that supplied the city and also the houses to the north of it. The remainder of the town south of the northern reservoir and some part of the lower Urakami Valley and the harbor area were virtually unaffected by contamination.

Blast effects were well marked for 2,000 meters north and south of the central detonation point in the Urakami Valley. Many peculiar concentration and skip effects were clearly evident, especially in a long series of steel frame buildings of the steel and torpedo works that ran north and south toward the harbor from the central area (figs. 299 and 300). Other stronger concrete and steel buildings had suffered obvious structural damage. Most concrete buildings had lost their steel window frames (figs. 301–303), which, it was evident, could become dangerous missiles inside the buildings.

In the Nagasaki Medical School, bodies were found entangled in the twisted window frames of the laboratory wing, which faced the blast. The contents of many rooms consisted of the wainscoting, the window frames, the ceiling, equipment, linens, and papers, which were all distributed over the floor (fig. 304) in a somewhat circular pattern. Many fuses had apparently been replaced with metal coins, and the fixtures hanging from the ceiling had therefore been violently twisted by the blast. The resulting short circuits had apparently lasted long enough to set the ceiling afire in many rooms, with the further result that the contents of the rooms burned along with the bodies of the staff. The prevailing wind carried the fire to the northeast part of the building, along the maple flooring and even up the maple treads of the staircase. The maple-floored ward areas on the upper floors were also burned but only downwind from the staircase.

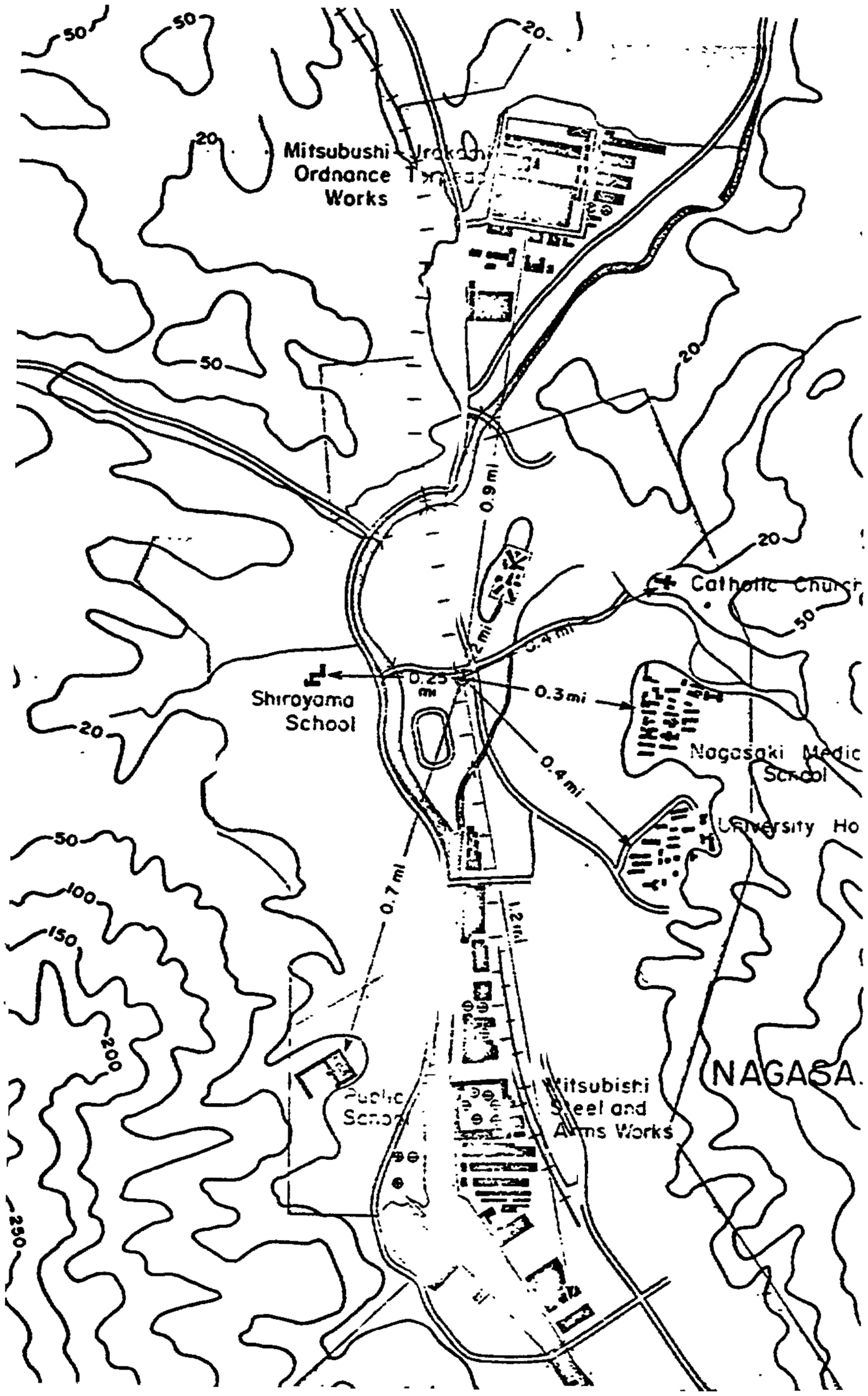
Many fires apparently occurred from similar short circuits. Overturned stoves caused many others. In both Hiroshima and Nagasaki there was considerable testimony to the effect that the fires started in multiple places at once but did not burn vigorously until about half an hour after the detonation.

The blast wave apparently put out the flames produced by infrared radiation in ripe brown wheat and smoldering wooden and dark surfaces before the fires from this source grew to any size.

Clinical Considerations

When the survey team arrived in both Hiroshima and Nagasaki, it found feeble evidence of first aid efforts. Injured casualties lay wherever any sort of roof offered shelter from the elements. Mats were laid on the floor, and the Prefectorial Government in charge of the country delivered rice and tea to the patients. Helmets had apparently been used for carrying water to them. Later, some of the supposed patients were obviously malingerers, who had come to the aid stations for foods.

From their own observations and from testimony of Japanese, members of the survey team divided the morbidity and mortality of the atomic bombs that were dropped on Japan into the following phases:



Map 13.—Outline map of Nagasaki, showing locatio

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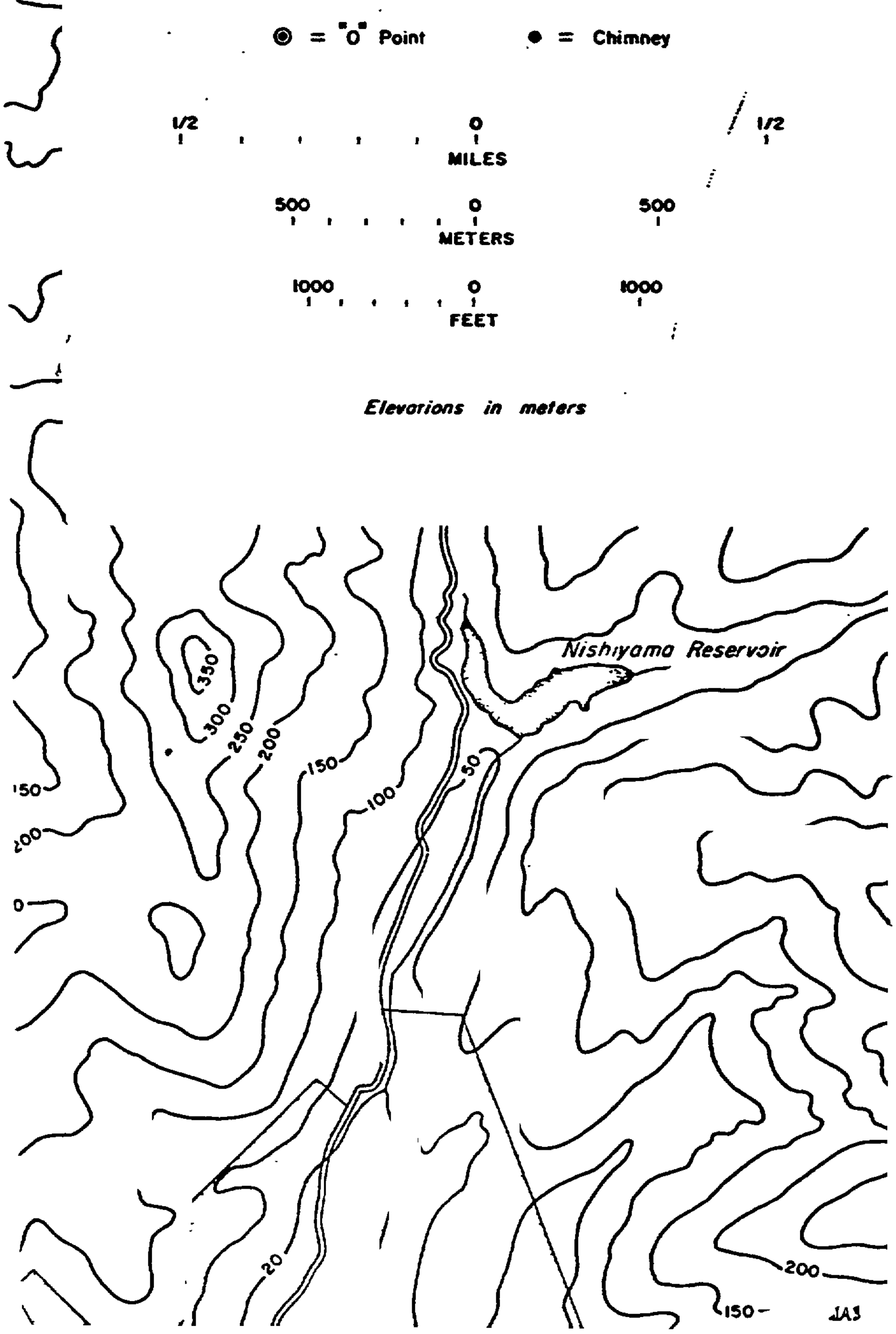

dings in which special casualty rate studies were made.

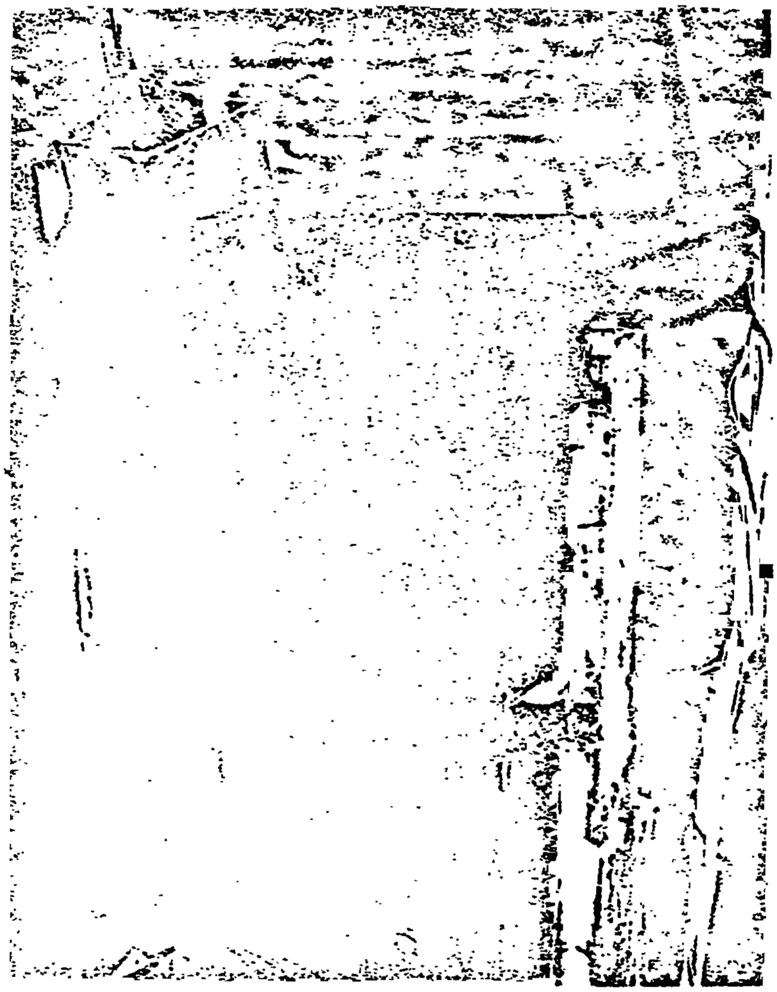

FIGURE 296.—Post and remnant of guard gate arm on railroad crossing directly under zero point at Nagasaki. Post is equally scorched on top and on all four sides, which shows that the heat came from above. Since the post was not consumed, it is evident that the fireball did not touch the ground.

1. Very large numbers of persons were crushed in their homes and in the buildings in which they were working. Their skeletons could be seen in the debris and ashes for almost 1,500 meters from the center of the blast, particularly in the downwind directions (figs. 305 and 306). The remains of large numbers of bodies were seen in poorly constructed trench shelters along the main roads. An occasional fresh body, with evidences of purpura, was found in ruined buildings. Collections of shoes (geta) were seen outside many of the first aid stations, where piles of human ashes were left from the extensive

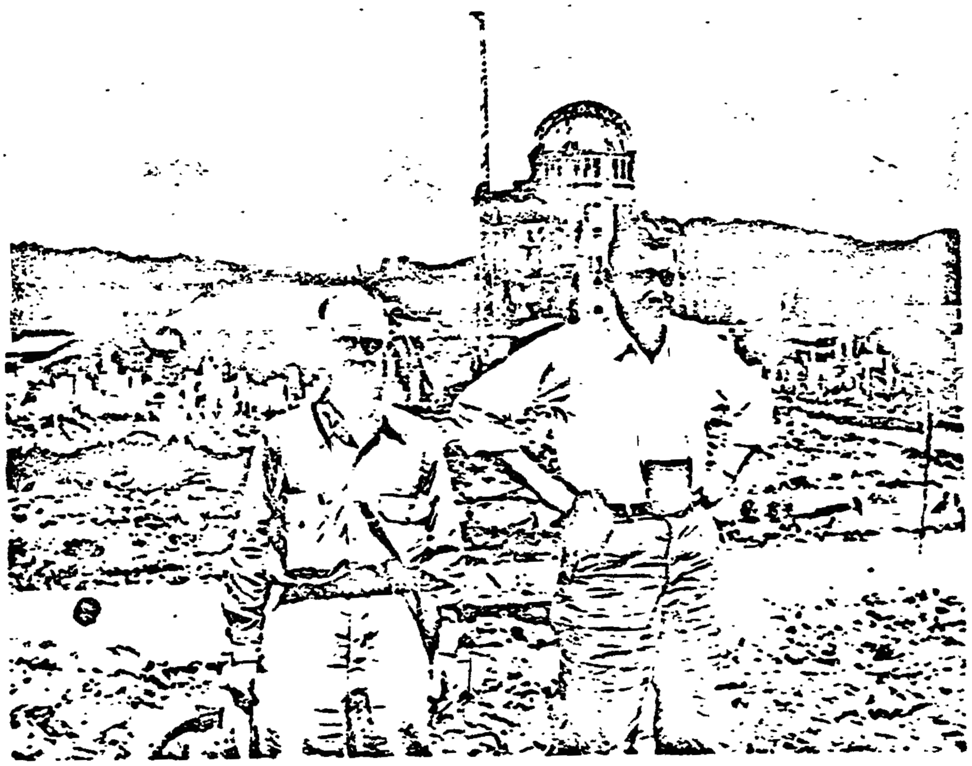

FIGURE 297.—Two members of the Atomic Bomb Casualty Commission, Dr. John S. Lawrence and Dr. Herman E. Pearse, Jr. visit ground center of atomic bomb detonation. Hiroshima, Japan, June 1947.

cremations carried out in the first few weeks after the bombings; all bodies were cremated, at first, for military reasons, to conceal the number of dead, and later to clean up the area for sanitary reasons. Parties from the Japanese Army and the Prefectorial Government were still searching for bodies as late as 25 September.

2. Large numbers of the population walked for considerable distances after the detonation before they collapsed and died. Many who crowded on the trains that left both cities several hours after the blast died promptly, and their bodies were taken off at the first and second stops.

3. Large numbers developed vomiting and bloody and watery diarrhea (vomitus and bloody feces were found on the floor in many of the aid stations), associated with extreme weakness. They died in the first and second weeks after the bombs were dropped. These manifestations gave rise to fear of typhoid and dysentery, neither of which developed.

Figure 298.—Telephone post at considerable distance south of zero point, Nagasaki, charred on side toward detonation. The fire apparently continued to burn for some time after the blast. Note that re-

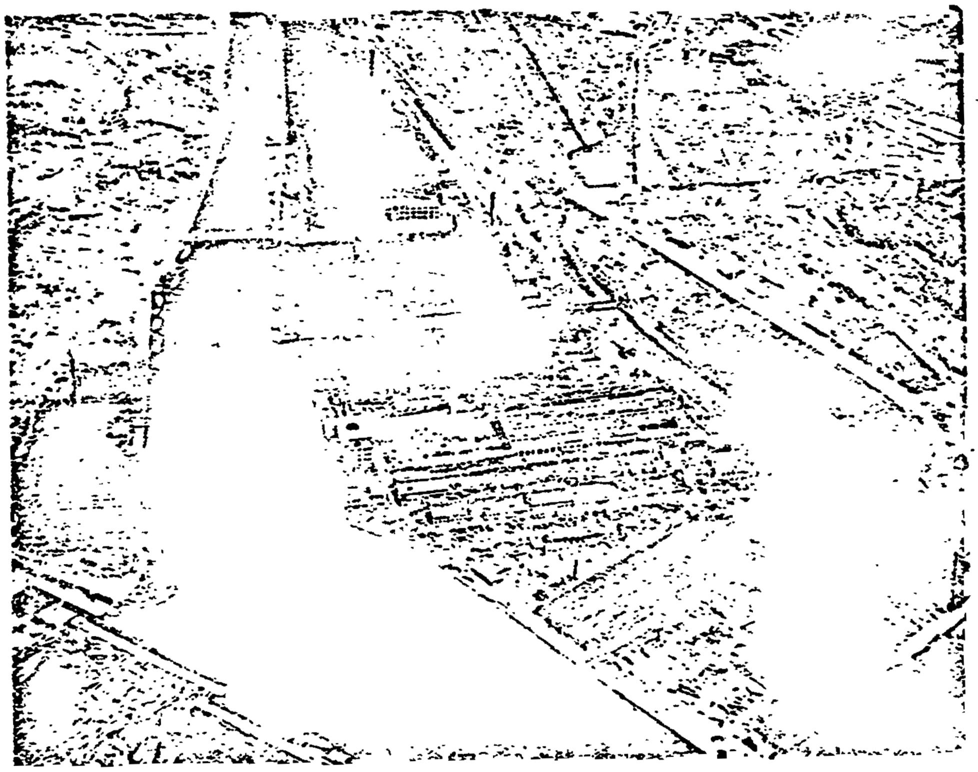

FIGURE 299.—Airplane view of south portion of blast area in Nagasaki, showing Mitsubishi Steel and Arms Works and other buildings shown in map 13. Just north of crossroad are two collapsed pattern works shown in figure 300. Steel frame buildings, as shown in figure 301, were generally denuded of their corrugated iron covers by the blast.

died within a few days after it appeared, but some of them were observed in the aid stations by the survey team. Deaths from purpura occurred a few days earlier and stopped a few days earlier at Hiroshima than at Nagasaki, but otherwise the reactions in both cities were much the same in respect to both clinical manifestations and timing.

Epilation (fig. 311), anemia, and purpura were only occasionally seen in general surviving population, the assumption being that radiation sufficient to cause these pathologic changes was likely to be lethal. Nonetheless, an occasional patient with purpura, particularly if it developed late in September, seemed to have some power of recovery.

6. The death rate after 20 September was much lower than in the preceding weeks, though many casualties continued to die from protracted anemia, secondary infection, burns, and other complications.

As soon as patients with bone marrow and other injuries died in the aid stations, the spaces they had occupied were filled with patients and with severe

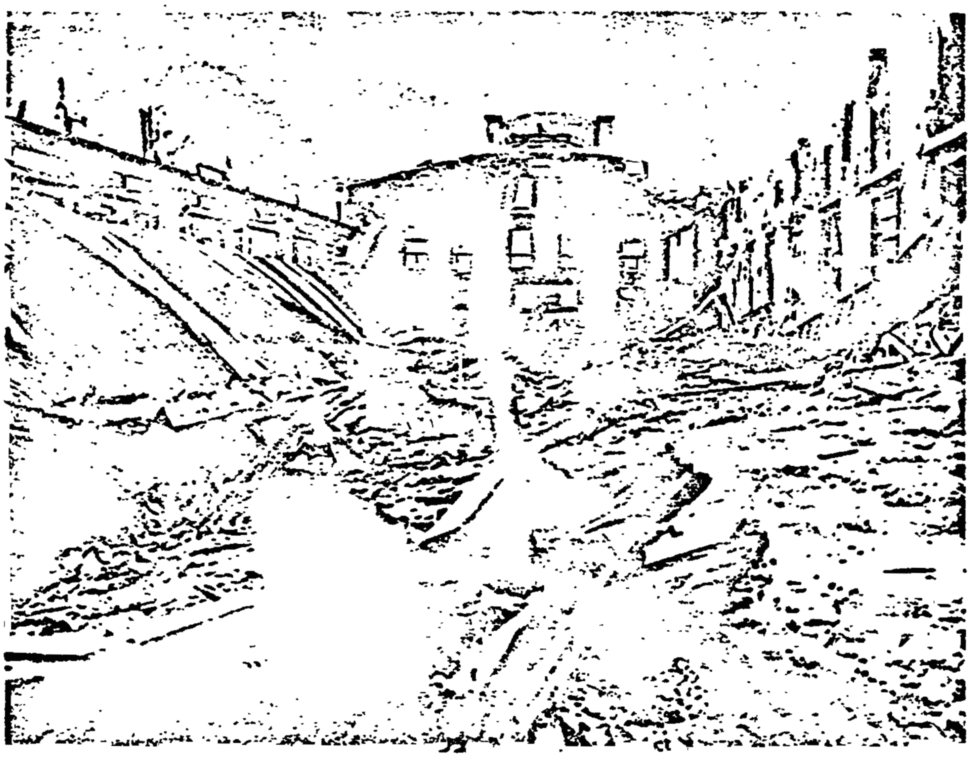

FIGURE 300.—Modern pattern works of German design at Nagasaki detonation of atomic bomb. The roof had collapsed upon about 300 workers in this building and in the similar building next to it.

burns who had survived and who were brought in by farmers and others of the local population, chiefly to take advantage of the rice and tea available there, as well as of occasional visits by physicians.

7. No count could be made of those who died outside of the devastated area, in public schools or other buildings to which they had been taken for care.

8. Occasional survivors (misses) in the devastated area showed little or no effects of radiation. Some of them had been in deep shelters or inside large buildings, but some escapes could not be explained.

9. The real mortality of the atomic bombs that were dropped on Japan will never be known. The Japanese had no accurate census at the time of the bombing. Afterward, no census was possible. Bodies were hastily cremated, as already mentioned. The destruction and overwhelming chaos made orderly counting impossible. It is not unlikely that the estimates of killed and wounded in Hiroshima (150,000) and Nagasaki (75,000) are overconservative.

FIGURE 301.—Interior of foundry building of Mitsubishi Steel and Arms Works shown in figure 299, about ¼ mile from zero point, showing chaos created by detonation, with torpedo molds and equipment thrown in all directions. Frame of building is grossly distorted, and its corrugated iron covering has disappeared.

Therapy

Occasional attempts to treat casualties showing bone marrow injuries with transfusions, plasma infusions, and penicillin were soon discontinued, chiefly because any needle puncture resulted in serosanguineous oozing that continued to death. Even pricks to obtain blood for blood counts caused oozing that could not be checked. It was thought that if the platelets were not too greatly reduced, because some functioning bone marrow was left, supportive treatment might be useful in carefully selected patients. If laboratory tests showed that the bone marrow was completely destroyed, the treatment available at the time the bombs were dropped on Japan was of no value at all.

OPERATION CROSSROADS

Planning and Implementation

The two bombs that were dropped on Japan in August of 1945 raised as many military and medicomilitary questions as they answered, and by the end

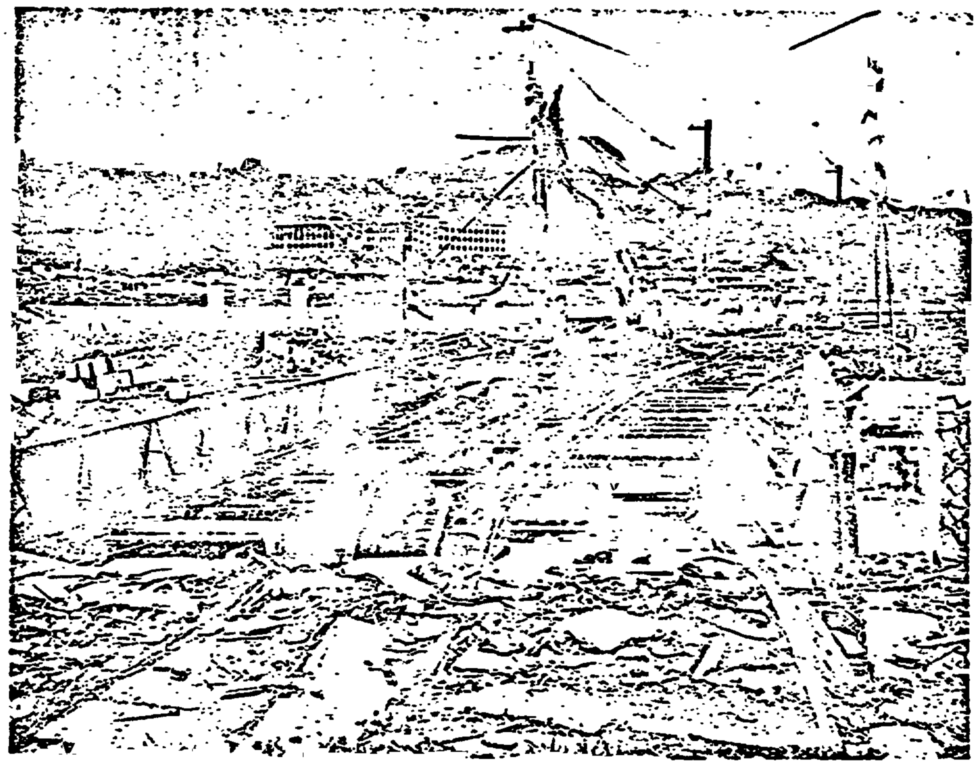

FIGURE 302.—Scene in Nagasaki 6 weeks after detonation, showing railroad bridge shifted by blast about 18 inches, enough to prevent trains sent out to pick up casualties from going further south. On the other side of the bridge is wreckage of streetcar which was apparently loaded with about 60 passengers. Across the valley, in the background, can be seen the crushed front of a building, empty at time of detonation. Note that all the window frames in front of the building are gone. Note also absence of ashes, indicating that there were no fires in this part of blasted area.

of the year it had become evident that the information needed concerning the tactical and other effects of such bombs on machines and men at war could be answered only by a series of tests under simulated war conditions (*46*, *47*).

The preliminary studies for these tests, which were known as Operation CROSSROADS, were conducted by the Joint Chiefs of Staff and led to the formation of a committee to investigate the project, with Brig. Gen. (later General) Curtis E. LeMay, AAF, as chairman. General Groves served as adviser to the committee. All the information collected in the Alamogordo test and in the Japanese bombings was carefully analyzed, and at General Groves' request, Colonel Warren, on several occasions, presented to the committee the observations he had made in Japan.

At the end of these deliberations, Vice Adm. (later Adm.) William H. P. Blandy, USN, was appointed to head JTF 1 (Joint Task Force One), which carried out Operation CROSSROADS on Bikini Atoll in the Pacific (fig.

FIGURE 303.—Interior of building shown in figure 302, with front wall displaced inward and window frames gone. There was no fire. Room has been cleaned by Japanese Army workers, but bench lathes exposed to weather are no longer usable. No information could be obtained on casualties among the workers who, if they were standing at workbench shown, were facing the blast.

312). Colonel Warren was assigned to the Task Force from the Medical Section, Manhattan Engineer District, to serve as radiologic safety adviser to Admiral Blandy and as Chief, RADSAFE (Radiologic Safety Section). On President Harry S. Truman's instructions to Admiral Blandy, Colonel Warren was to safeguard what was eventually a 42,000-man operation from the "peculiar hazards" of the atomic bomb and was to devise a radiologic defense organization and pattern for both military and civilian operations. At the end of the JTF 1 Operation, it could be said that no one had been injured by the "peculiar hazards" inherent in it.

Personnel.—The original RADSAFE group was made up of monitors and laboratory personnel capable of measuring radiation in air, water, and other materials. Experts in plotting, radio communication, and transportation were assigned later. During the 6 months of intensive planning and testing that followed the decision to conduct Operation CROSSROADS, cooperation among its components—the Armed Forces, university personnel, industrial contractors, and others—was almost ideal. Though each branch of the

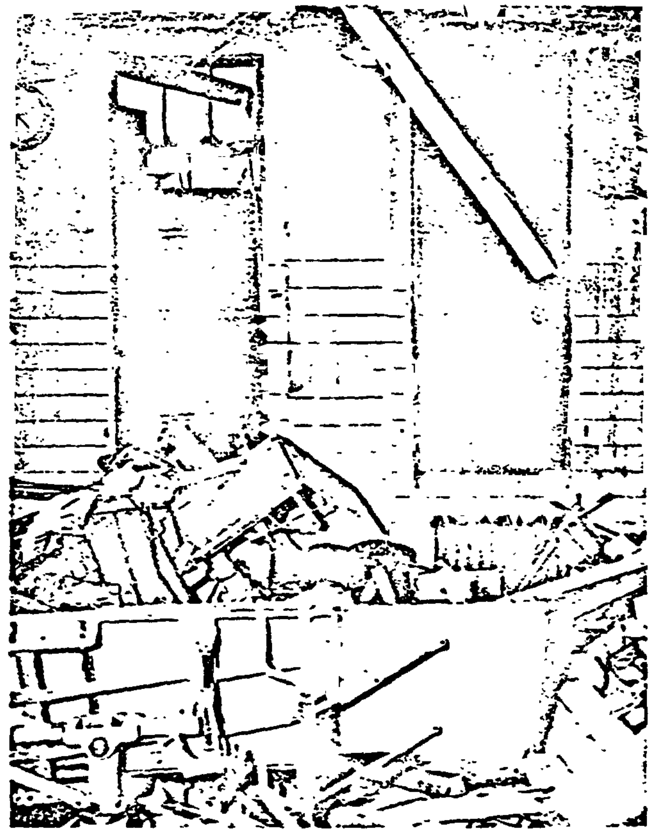

FIGURE 304.—Urology clinic in medical school at Nagasaki 6 weeks after detonation of bomb, showing disarrangement of furniture and equipment. Ceiling soundproofing is torn off and scorched by fire that apparently started at base of ceiling fixture and was caused by violent oscillations of lamp and short circuit at its base. Fuses had been replaced by coins, and the short circuit ignited the cornhusk soundproofing which did not, however, burn sufficiently to drop embers on floor and start fires which occurred for this reason in other parts of the building. No bodies were found in this clinic.

Armed Forces had its special role in the operation, personnel were assigned for their technical skill alone.

Manpower was a major problem. The war was only just over, and the men needed for this operation, like all others who had been in service or participated in the war effort, did not care for the idea of spending 2 months or more on a tour of duty at sea or on a hot tropical island.

Eventually, however, the necessary personnel were secured. Monitors numbered 480, and the total RADSAFE force, with the crews of the monitor-

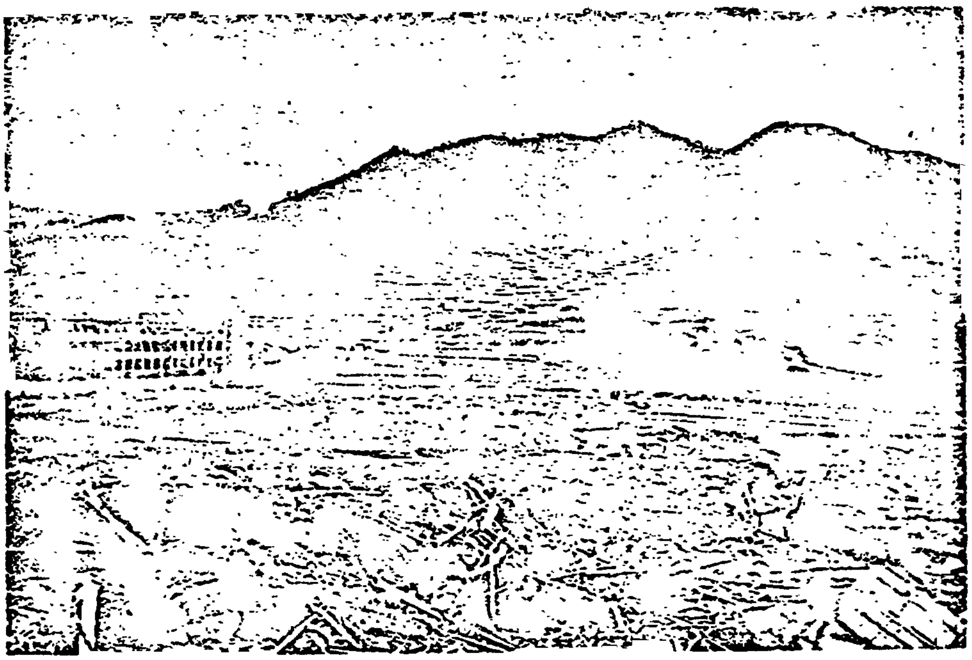

FIGURE 305.—View of Nagasaki 6 weeks after bombing, showing Roman Catholic Church that escaped heavy casualties because Mass had ended an hour earlier. Only parts of heavy brick walls still stand. Boxlike structure seen at bottom of hill to the left is the cupola. In far left is a school, whose upper story shows a slanting displacement. Building was used for industrial purposes at time of bombing, and no data could be secured concerning casualties among the work force. Shacks in foreground were constructed after bombing. Kindling in foreground is in an unburned area. The ground between this area and background is covered with ashes of houses, in which are skeletons consumed by fire within them.

ing boats and planes, numbered about 3,500. Capt. (later Maj.) Robert J. Buettner, MAC, who was assigned from the Medical Section, Manhattan Engineer District, to be executive officer (fig. 313), deserves great credit for his procurement of personnel and for other implementation of the plans.

A hard core of monitors and supervisors was trained on the U.S.S. *Haven* during the voyage to Bikini (map 14) which was reached on 12 June 1946. Almost all RADSAFE personnel were landsmen, and part of their onsite training was devoted to teaching them to get into and out of small taxi boats while they were loaded down with sensitive and very precious instruments.

Supplies.—Colonel Warren undertook to procure the necessary radiation detection instruments, film badges, metal foils, and other measuring devices (fig. 314), which at this time were made by only a few contractors and were in short supply. Geiger-Müller counting tubes, which were then made by hand in the laboratory at the University of Chicago and later by the Victoreen

FIGURE 808.—Devastated area, facing west, in front of medical school at Nagasaki. Roadway has been cleared by Japanese Army and access to school buildings still standing is now possible. Shown in foreground are tiles and other remnants of burned buildings and houses in the area. Several large concrete bathtubs are visible. In immediate foreground are clusters of ashes and other remnants.

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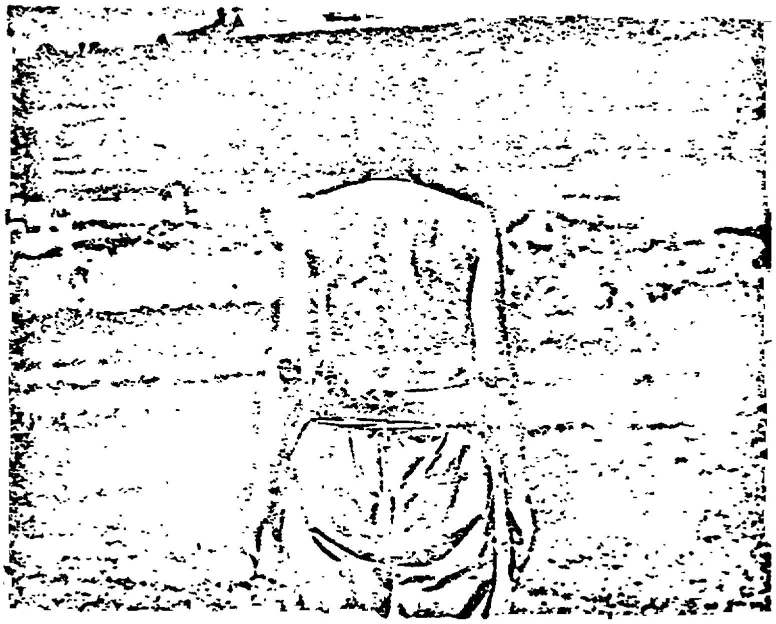


FIGURE 307.—Healed flash burn of back. This man, wearing khaki cotton clothing, was standing in the open, as shown in posed photograph. The blast threw him to the ground, and his cotton clothing was scorched and destroyed. His burns healed, and he recovered from mild radiation symptoms which he showed. This view shows scars of healed flash burns on back, elbows, and lateral aspect of right arm. The rest of the body was unhurt. Note huts in background, built for temporary housing after bomb was dropped. Note also, on horizon, trunks of trees denuded of branches by blast. Bushes and grass in ditch have begun to grow.

Instrument Co., had to be shipped weekly to Bikini during the second (BAKER, underwater) test in order to keep up with the repair rate. Some equipment was improvised (fig. 315).

Because of the large number of men RADSAFE would employ, a laboratory and headquarters ship was absolutely necessary if the target area were to be properly covered. The hospital ship, U.S.S. *Haven* was assigned for this purpose. It was refitted with special radiation laboratories and with instrument-calibration and electronic repair facilities. An 18-channel radio communication center was also installed.

Operating procedures.—The factual information required for the preparation of the operations manual, "Annex Easy," and the directions for the techniques of monitoring procedures were painstakingly written in Washington by Capt. George M. Lyon, MC, USN, who served as safety consultant and later as Chief, Bomb Safety Section. Colonel Warren, Colonel Friedell, and occasionally the medical consultants of the Manhattan Engineer District frequently conferred with him on the content of the manual.

FIGURE 308.—Purpura hemorrhagica in Nagasaki after atomic bomb was detonated over city. A, B. Purpura hemorrhagica of moderate severity. Both children show effects of bone marrow damage; child in view B is obviously in extremis. Hemorrhagic spots, while well distributed, are small and discrete. They show most prominently on arms in view A and on legs in view B. C. Forearm of Japanese woman with skin lesions and remnants of vesicles which did not become confluent. Note few small, discrete, black, hemorrhagic spots.

In the spring of 1946, all safety procedures were coordinated with the staff of JTF 1. President Truman had directed Admiral Blandy to "see that no one gets hurt," and it was the function of RADSAFE of the operation to be present at all Task Force activities and to stand guard with their Geiger counters to detect invisible dangers from radioactivity. The whole operation was enormously complex.

FIGURE 309.—Generalized petechiae in patient obviously near exitus, 6 weeks after bomb was dropped. This finding was associated with profound leukopenia and thrombocytopenia and was usually accompanied by other signs and symptoms of bone marrow damage. Note subcutaneous extravasation of blood and bleb caused by bleeding around needle puncture wound at elbow. The wound did not close by the normal clotting mechanism and sufficient serosanguineous fluid oozed from it to saturate the mat. Large numbers of casualties died in this manner during the fifth and sixth weeks.

Test ABLE

Test ABLE, which took place on 1 July 1946, was an airdrop of unspecified altitude. It sank several of the largely obsolete ships that composed the target field. The mushroom cloud formation, by now familiar to all, occurred as in all previous drops of an atomic bomb.

As soon as it was considered safe—about half an hour after the drop—

FIGURE 310.—Patient with extensive purpura and sordes 2 hours before exitus. Note extensive epilation of scalp, with eyebrows and eyelashes still intact. This man was picked up about 2,000 meters from center of detonation; the picture was taken on 3 September 1945.

monitoring planes flew over the target area to determine radioactive densities. Within 12 to 24 hours after the drop, most of the remaining ships of the target fleet were considered radiologically safe. Monitoring crews (fig. 316) were dispatched to the lagoon in groups of four fast taxi boats, each group under the control of an LCT, which communicated the water surface and hull radiation measurements by radio to the U.S.S. *Mt. McKinley*, the flagship of the fleet, as they were received from the crews. The measurements were plotted in a command post on the flagship. Water samples were collected at specified points and analyzed on the U.S.S. *Haven*.

Task Force personnel in tugs and larger vessels followed the first monitoring boats into the lagoon and boarded the target ships to obtain instruments that had been left on them and to assess the bomb damage. One or more monitors accompanied each boarding party and preceded it aboard, to make certain that there was no contamination or that radioactivity was low enough to be safe.

The film badges worn by all personnel were returned to the U.S.S. *Haven* every night, for development and measurement. Radiation exposures were measured and recorded for all personnel as individuals and as groups. Certain fixed badges, as well as metal foils, soap (because of its sodium content), and certain drugs (silver nitrate, arsenic, phosphates) in the ships' pharmacies were recovered from critical locations in the target ships. Those in close-in ships all showed radioactivity from the bombardment, and it was concluded that lethal doses would have been received by many of the ships' companies, even in the heavier ships, such as the U.S.S. *Nevada*, if the ships had been close to the target area.

Test BAKER

Test ABLE was a shakedown for the monitoring operations of the second underwater test (Test BAKER), and many improvements in procedure were introduced in anticipation of the more severe contamination expected in it. Additional personnel were flown to Bikini before it. New measurements were planned, and additional equipment, including deep underwater Geiger counters, was secured. Dr. Dowdy, responsible investigator for the Manhattan Project contract at the University of Rochester, rendered great assistance in these matters, as he had for Test ABLE.

Test BAKER was carried out on 25 July 1946. Nine ships were sunk when the bomb was detonated under water, and the radioactive contamination of the ships not sunk was extreme and in many instances apparently permanent: it could not be removed by any means.

The immediate effect of the detonation was a lethal radioactive mist, about 3 miles wide even upwind, which developed under the great mushroom cloud of water and steam that formed immediately after the bomb exploded. This mist drifted north across the target area, crossed the reef between Bikini and Aomoen Islands (map 14), and then went out over the ocean, where the radioactive fallout was soon lost or dispersed by the vigorous action of the waves.

Radioactivity was so high on the surface of Bikini Lagoon that for some hours it was not possible to go into the target area beyond the periphery to examine the ships. Later attempts to wash the ships down were futile, even when detergents and alkalis were used. At first, tugs could not be brought alongside them for more than 20 minutes at a time. Later, when the ships could be boarded, the length of the stay on board had to be strictly limited. It was soon clear that many of the most contaminated ships would have to be sunk or be towed away to Kwajalein (largest of the Marshall Islands) or, later, to the west coast.

All the water in the lagoon remained highly contaminated, because of the presence of the highly contaminated water at the detonation site. Rope and rusty surfaces exposed to the water soon became highly contaminated also.

Clothing was quickly contaminated in the course of the investigations and was soon in short supply. Rusty radioactive water dripping off the superstructures of the contaminated ships left residual stains, even after the clothing had been laundered, and a good deal of it had to be confiscated because it could not be cleaned. Boots and shoes tracked contamination from the ships onto the tugs, and the footgear had to be discarded also. A change tug, to serve the purposes of the changehouses at Los Alamos and other laboratories (p. 865), improved the situation but did not entirely solve the problem.

FIGURE 311.—*See opposite page for legend.*

A wide variety of weapons and equipment used by the Army was exposed during Test BAKER, under the supervision of Maj. Gen. (later General) Anthony C. McAuliffe, Army Ground Forces. RADSAFE furnished monitoring services, especially in Test BAKER, in which many instruments and much of the equipment were in such highly contaminated areas that special monitoring and cleansing procedures were necessary before they could be recovered.

Marine and animal studies.—The details of the scientific data collected in Test BAKER cannot be related here, but special mention should be made of the comprehensive studies of the Marine Biologic Group under the direction of Prof. Lauren Donaldson of the School of Fisheries, University of Washington (p. 878), assisted by Arthur D. Welander, Ph. D., and Charles F. Pautzke, Ph. D. Their investigation of the radioactivity of all sorts in the lagoon, from plants, seaweed, corals, and shellfish (fig. 317) to herbivorous and carnivorous fishes, showed all of them to be contaminated to some extent. This was a most important finding, for it made all of these fishes unfit for food. It also introduced the possibility, if not the probability, of the spread of contamination as larger uncontaminated fish ate smaller contaminated fish in an endless cycle.

Termination of Operation CROSSROADS

The third test planned for Bikini, Test CHARLIE, which was to be a deep water detonation, was canceled in September 1946. Test BAKER had shown clearly that an underwater detonation of an atomic bomb would create lasting problems from the radioactive fission materials produced by it, not only because of the involvement of surface vessels but also because of the continued radioactivity in the crater area, which would continuously add to the radioactivity already present in the lagoon. The health problems, aside from the economic problems, which could be created by the detonation of an atomic bomb in a large harbor were beyond calculation or even imagining.

After Test CHARLIE was abandoned, Colonel Warren appointed a civilian committee (composed of Dr. Robert Newell, Dr. Robert Rodenbaugh,

FIGURE 311.—Epilation in survivors of Nagasaki atomic bombing. A. Acute epilation, 1 month postexposure. B. Acute loss of scalp hair, with eyebrows and eyelashes intact. Note extensive purpura (30 August 1945). C. Almost complete loss of scalp hair. Note that eyebrows, mustache, beard, and hair on neck have not been affected. D. Almost complete epilation of top of head. Eyebrows and eyelashes intact. Purpuric lesions in skin of face and on upper lip. Hemorrhagic area in lower lip. Evidence suggests that this picture was made about 4 weeks postexposure. E. Epilation with very sparse regrowth of coarse hair. F. Slight amount of permanent epilation over upper part of scalp caused by X-ray radiation. Scalp above ears and neck was not protected by cap, and side of head, down to neckband of shirt, is badly scarred from infrared burns. Skin and cartilage of the ear escaped severe injury, which is unusual.

FIGURE 312.—News conference on U.S.S. *Appalachian* during Operation CROSSROADS, summer 1946. In foreground, Admiral Parsons, USN, Gen. William E. Kepner, USA, and Vice Adm. William H. P. Blandy, USN; at microphone, Col. Stafford L. Warren, MC; in background, Capt. George Lyon, MC, USN.

Dr. Failla, and Dr. Eugene P. Pendergrass) to determine which ships could be brought back to the mainland. In August, after the scientists had obtained their instruments and data from the target ships and Joint Task Force One began to prepare to leave Bikini, Admiral Blandy appointed Rear Adm. F. G. Farrington, USN, to select the ships to be saved or towed to Kwajalein and to arrange for sinking the rest. When most of the RADSAFE personnel departed in the U.S.S. *Haven*, Colonel Warren left Lt. David Bradley, MC, to monitor the vessels to be towed to Kwajalein.[6]

The remainder of the RADSAFE party returned to San Francisco in September, on the U.S.S. *Henrico*. During the voyage, Captain Lyon organized a Radiologic Safety School, which was the first such course ever

[6] Lieutenant Bradley's "No Place to Hide" is an extremely vivid account of the Bikini experience (48). The book makes very clear what an atomic bomb can do to ships, water, marine and animal life, and, by extension, to human beings.

FIGURE 313.—Col. Stafford L. Warren, MC, and Capt. Robert J. Buettner, MAC, in Radiologic Safety Section office, Operation CROSSROADS, summer 1946.

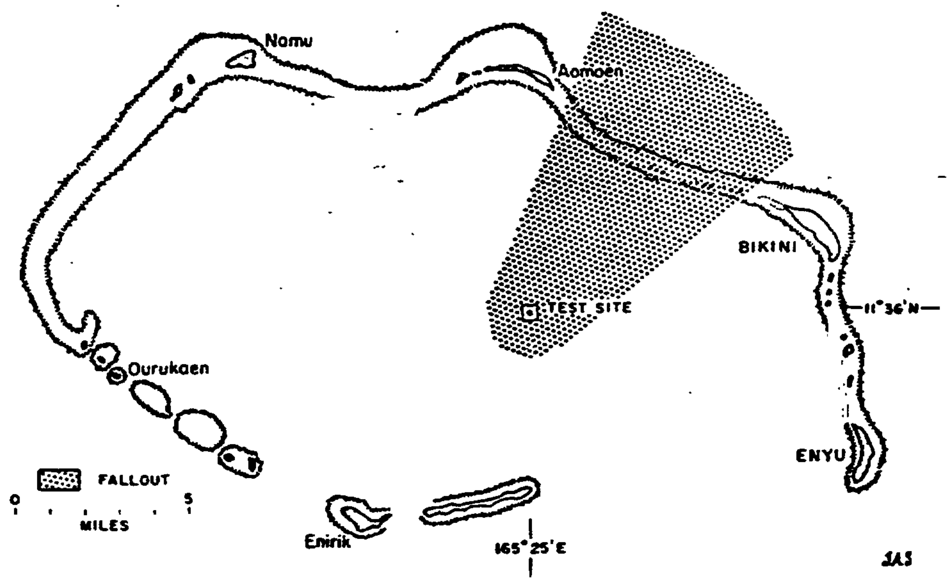
given and which served as the nucleus of a similar expanded (4-week) course later given in Washington.

When Colonel Warren was separated from service on 6 November 1946, after spending his time between that date and his arrival in San Francisco from Bikini on 7 September 1946, on the final details of the RADSAFE part of JTF 1, he became temporary civilian Chief of the Medical Division, Atomic Energy Commission. He served in this capacity until he was replaced by Dr. Shields Warren in February 1947.

CONCLUSIONS

At no time during the period between 1943 and 1946 were facilities allotted, or time provided, for the Medical Section of the Manhattan Engineer District to prepare a comprehensive history of its activities. The material in this chapter is a running account of the program, chiefly derived from memory and supplemented by only a few records. Regulations forbade notetaking. Official records were scanty. There were few charts and photographs. Many dedicated workers in both universities and industries which participated in the atomic bomb development have undoubtedly been omitted from this account because of the paucity of formal sources.

No one caught up in the excitement and drive of the Medical Section, Manhattan Engineer District, program could ever again be quite the same.



Map 14.—Bikini Atoll, from which Operation CROSSROADS was conducted. Note fallout pattern.

Other laboratory and industrial programs carried out during the war were perhaps similarly stimulating, but this program was of such a special nature that it left its permanent mark on those—and there were many—who were intensively involved in it.

Most of the medical and other personnel, including biologists, biophysicists, and health-safety personnel, who were engaged in this program have continued in the field of atomic science since the War. Many worked in the newly established Atomic Energy Commission. Many of those who returned to their former university positions or their former industrial environment have retained their interest in this new field and have worked on the application of the knowledge derived from it to education and further research.

The speculative imagination of the workers in this program was greatly stimulated by their wartime occupation. Few, however, at the end of the war could have conceived the real extent of the use of isotopes and of the allied knowledge in medicine, biology, and industry that has come about since the end of World War II. To those who had both the privilege and the responsibility of carrying out the tasks so briefly outlined in this chapter, it would seem that little imagination is required to accept the fact that nuclear weapons can be the ultimate destructive weapon for all mankind, and that the way to peace, unclear and difficult to attain though it be, must somehow be attained by the people of the world.

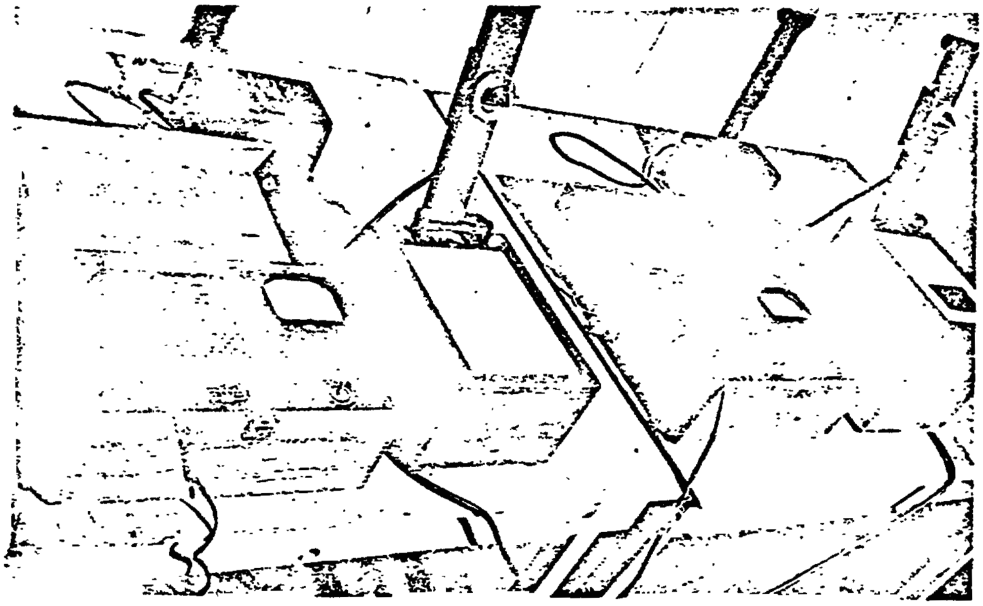


FIGURE 314.—Densitometers used by Photometry Division in Operation CROSSROADS.

FIGURE 315.—Personnel of Operation CROSSROADS, studying 3-dimensional model of radioactivity fallout pattern from surface to tropopause. This improvised, admittedly crude, piece of equipment, was really more efficient than more elaborate and more expensive items.

Figure 316.—Dispatching room, U.S.S. *Haven*, during Operation CROSSROADS, summer 1946. Equipment is being issued to monitoring personnel.

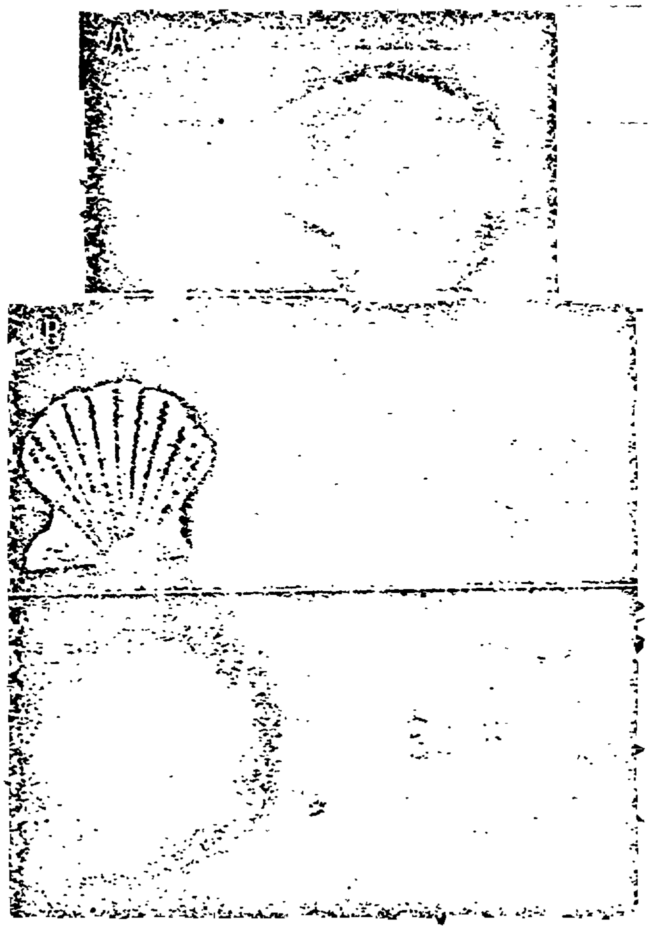


FIGURE 317.—Biologic materials collected from water of Bikini Lagoon after underwater (BAKER) detonation. All grasses, sponges, shells, shellfish, and other fish became radioactive at once and so remained, particularly in eastern or crater portion of lagoon. A. Autoradiograph of surgeonfish caught in lagoon after detonation of bomb. Digestive tract contains radioactive materials picked up in food. Vertebral column and bony orbit can be seen. B. Shells recovered by divers off hull of U.S.S. *Saratoga* on 29 July 1947, 1 year after Test BAKER. Each shell is extremely radioactive, as can be seen from its autoradiographic image (bottom). Radioactivity has slowly increased with passage of time.

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