# SPECIAL FEATURE

## HIROSHIMA, NAGASAKI, AND THE RERF

# Hiroshima, Nagasaki, and the RERF

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AT 1:45 AM ON MONDAY, August 6, 1945, two scout planes took off from an airfield on Tinian Island in the Marianas. They were followed a few minutes later by one bomber. Their orders were to head for Hiroshima. If it was cloudy there, they were to continue on to Kokura and if again poor weather was encountered, make for Nagasaki. Hiroshima, with a population of 300,000, was first on the list because it had not been previously bombed, was constructed on a large, flat delta surrounded by mountains, served as the headquarters of the Second Army, and was a major military staging area for Southeast Asia. Shortly before 8:00 AM the planes were spotted at Hiroshima and air raid warnings were sounded. As the weather scouts passed over and continued on, the all-clear signal was given. The weather was perfect, with almost unlimited visibility. At about 8:14 AM the *Enola Gay*, carrying the atomic bomb, appeared. Because there was no squadron of bombers and because the first planes had passed on, no air raid warning was sounded. At 8:15 AM the bomb was dropped and exploded at 1800 feet with power equivalent to 12,500 tons of TNT. Forty thousand buildings (80% of the total) were destroyed. The actual number of casualties at Hiroshima is not known, because detailed records accounting for the large number of military personnel were not available. Among the civilians in the city, 64,600 died within the first few months of burns, concussions, and radiation. It has been estimated that chances of survival were 0% at ground zero, 25% at 3000 feet from the epicenter, 50% at 4000 feet, and 95% at 6000 feet (over 1 mile). The second bomb was destined for Kokura three days later, but because of cloudy weather there, it was dropped on Nagasaki instead. Some 39,000 people were killed. Despite the fact that the second bomb was more powerful, mortality in Nagasaki was lower because the mountainous terrain protected parts of the city from direct exposure. The first bomb had released a considerable number of neutrons, while the radiation from the second bomb was largely composed of gamma rays, which travel further (up to 7500 feet) and penetrate more deeply.

The three principle impacts of an atomic bomb explosion above ground

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are thermal radiation, air blast, and ionizing radiation. While this account will focus on the long-term effects of the latter, the other impacts were immense. (At this point let us remember that we are talking about bombs that were very small indeed by present-day standards. The bombs carried by current ICBMs are 30–40 times as powerful!) Figure 1 shows a two-story, steel-frame building with seven-inch, reinforced concrete walls. It stood 0.4 mile from ground zero at Hiroshima. With the buckling of the walls, the entire second story dropped to the ground. Obviously, the effect of such an air blast on wooden frame houses was catastrophic, even at far greater distances. Concerning thermal effects, paper, cloth, and dry wood were ignited at distances up to 3500 feet from ground zero. To complete the devastation there was a fire storm. Fire storms, which were not confined to nuclear bombs but were also encountered in the saturation incendiary bombing of Tokyo and of several German cities, notably Dresden, are caused by the countless, scattered, individual fires. Their updraft produces a strong wind moving from the periphery toward the center of the city, a phenomenon possibly accentuated in the case of the atomic bomb by the mushrooming effect. Almost immediately, virtually the entire center of the city of Hiroshima became an enormous bonfire. (In the museum at Hiroshima many of the exhibits, such as melted glass, melted metal pots, and fused nails, were caused not by thermal radiation, as the exhibit implies, but by the fire storm.) It has been estimated that in the first few weeks after the explosion, air blast, fire, and nuclear radiation accounted about equally for the casualties. It is not widely known that the sudden updraft of hot, moist air to the cooler heights resulted in condensation and the "black rain" that poured down on both cities later in the day. The raindrops, containing much smoke and dust, hence black, were highly radioactive. Mortality figures specific for this fallout are not known.

Regarding fallout, there are many components rendered radioactive in the dust drawn up from the earth by the mushroom effect of the explosion. In Nevada tests, for example, some 300 different isotopes have been identified. Many of these have short half-lives and thus are active only for brief periods after the explosion. Examples are iodine-131 (8 days), sodium-24 (15 hours), manganese-56 (2.6 hours) and silicon-31 (2.6 hours). At the other end of the scale is carbon-14, with a half-life of 5,730 years. Between such extremes are strontium-90 (27.7 years) and cesium-137 (30 years). Iodine and strontium deserve special mention. The former is concentrated in the thyroid gland and may be ingested for a considerable period of time by drinking milk from cows eating contaminated foliage. Strontium, which constitutes a large fraction of the fission product, localizes in bone. For every 1000 atoms undergoing fission, 30–40 atoms of strontium-90 are formed. When all of the above is averaged out in terms of total fallout at, or near, the bomb site, it has been determined that if the radiation dose rate at 1 hour is taken as the reference point, then at 7 hours the rate will have decreased to 1/10 of the reference value, at 2 days to 1/100, and at 14 days to 1/1000. These factors, of course, will vary greatly, depending on the type and height of the bomb as well as the wind velocity. Of interest in this connection is the fact that epidemiologic studies of persons who moved to Hiroshima and Nagasaki in the months and years following the explosions have not shown an increased cancer incidence.

For all subsequent radiation studies it became essential to know certain basic data. On every bombing mission the Air Force keeps records of bombing altitude, wind speed, approach direction, and air speed. In the case of the the atomic bombings, as John Auxier of the Oak Ridge National Laboratory has so succinctly stated, "The records of the two most important bombing missions in history are incomplete and inaccurate to a degree beyond comprehension." Therefore, most of the information had to be assembled from discussions later with the plane crews and Japanese eyewitnesses and, perhaps more important, ground studies of shadow angles and residual radiation. To indicate some of the difficulties, it might be worth recounting an episode cited by Auxier. One of the most active radiation experts at the site was Dr. Sakae Shimizu of Kyoto University, who, on learning of the disaster, made his way as quickly as possible to Hiroshima with a crude but workable Geiger counter and recorded innumerable measurements. He also collected photographic film from camera shops and sulfur from insulators on telegraph poles to determine the intensity of radiation at different distances from ground zero. Unfortunately, Dr. Shimizu was still at it when the U.S. military occupation forces arrived, and he looked pretty suspicious creeping around and jotting mysterious symbols in notebooks. An officer therefore confiscated all his books, giving the doctor a signed receipt. Through this receipt, the officer was identified 12 years later in civilian life. He told his interviewers, however, that when he left Japan, he had given the notebooks to another officer, whose name he could not remember. The notebooks have never been located. There were, of course, other scientists, both Japanese and American, doing much the same thing, and through such studies the height and location of the bomb and some parameters of air blast as well as of thermal and nuclear radiation could be estimated. But reasonably accurate calculations of nuclear radiation, upon which the significance of medical effects would directly depend, were lacking. This was particularly true for the civilians exposed within houses that became nonexistent.

The Army of Occupation established a Joint Commission of Japanese and American Scientists to gather initial data to determine the immediate medical effects of radiation. A. W. Oughterson, Shields Warren, and Stafford Warren played a prominent part in these early studies. It soon became evident, however, that a more integrated effort over a considerable period of time would be necessary. On November 18, 1946, in a letter to President Truman, James Forrestal noted that "a conference group of the Division of Medical Sciences of the National Research Council convened to discuss the problems." He then quoted their recommendation, to the effect that the President should direct the National Academy of Sciences (NAS) to "undertake a long-range, continuing study of the biological and medical effects of the atomic bomb on man." Across the bottom of this letter is handwritten the word "approved," beneath which are the President's signature and the date, November 26, 1946. With funds provided by the U.S. Atomic Energy Commission, the Atomic Bomb Casualty Commission (ABCC) was established. This had the advantages of drawing upon the reputation and scientific expertise of the NAS and of avoiding charges of bias, which might have arisen if the military or any federal agency had been conducting the research.

Concerning those early years, allow me to quote R. Keith Cannan, a former chairman of the Division of Medical Sciences of the National Research Council:

> The task facing the ABCC in the early years was formidable. To establish operations in two devastated cities, it had to locate housing as well as clinical and laboratory facilities, and mobilize American and Japanese physicians, nurses, statisticians, technicians, interpreters, and field workers. The local national machinery for administering community affairs had to be learned. But above all, it was necessary to secure the good will of the survivors—people who spoke an unfamiliar tongue and followed an alien culture, who had lost members of their families, relatives, and friends, their homes and their accustomed occupations—people with little left to them but their memories.

It might here be added that "to secure the good will of the survivors" was a problem compounded by building the facility in the midst of a military cemetery in a city park on a high hill looking down on Hiroshima. This site it still occupies (Figure 2).

To continue to quote Dr. Cannan:

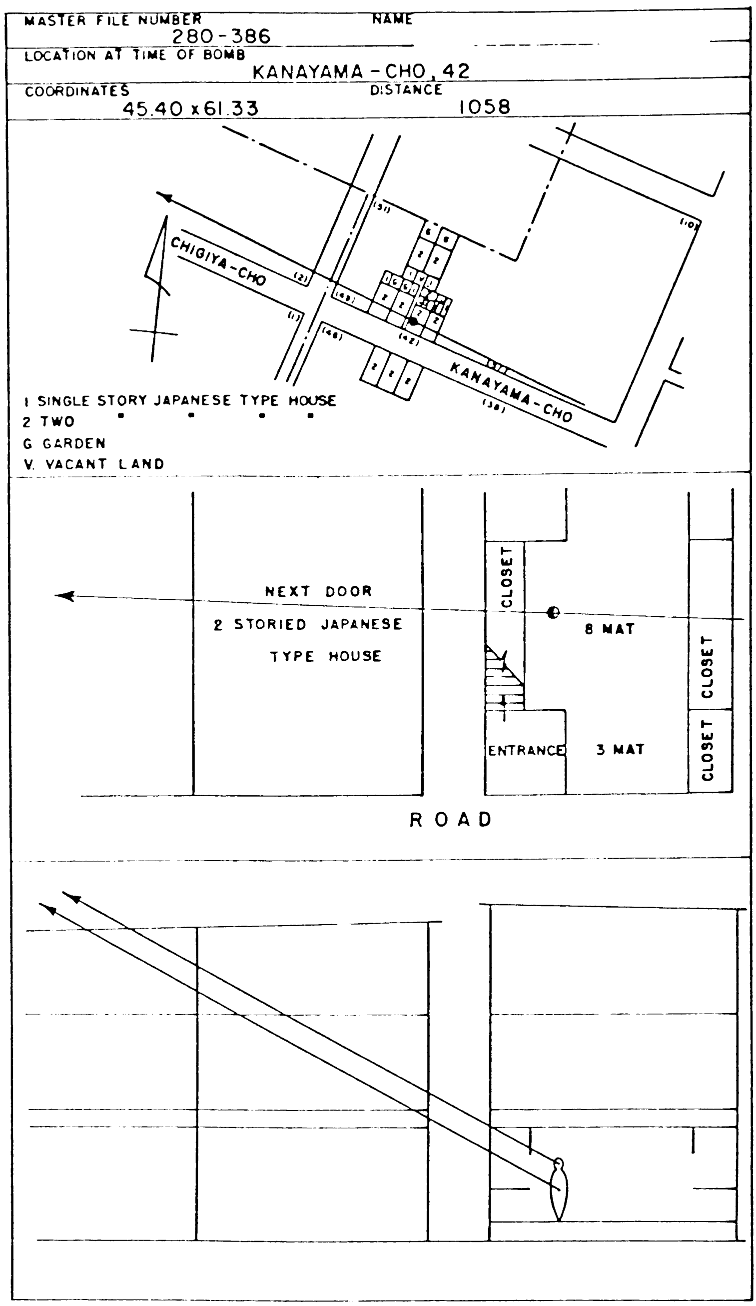
> The early years of ABCC were spent building up resources and groping toward a coherent program. Not knowing the kinds of delayed effects that might be encountered, a

> broad strategy was followed. Searches were initiated for new diseases uniquely associated with radiation, altered incidences of known diseases, and changes in physiological status without overt disease. . . . Growth and development of individuals exposed in childhood were studied. In addition, the incidence of cataracts and of leukemia and other blood dyscrasias in children and adults were surveyed.

In 1955 a committee consisting of T. Francis, S. Jablon, and F. Moore was asked to examine the program. The resulting "Francis Report" recommended a unified study focused on a fixed population and utilizing systematized epidemiologic follow-up studies, which became the basis for most of the subsequent work.

As the research continued it became increasingly apparent that a binational foundation should be established, with equal governance, staffing, and funding by Americans and Japanese. Accordingly, the Radiation Effects Research Foundation (RERF) was established in 1975 with financial support from the two governments. There is a Board of Directors and a Science Council of equal number by nationality. The American members are nominated by the National Academy of Sciences and the Department of Energy.

So much for this brief history. Let us now turn to the information acquired since 1950. The only way in which adequate dosimetry could be obtained was to build several typical Japanese houses (Figure 3) containing monitors, locate them at varying distances from ground zero, and measure the attenuation of radiation during explosion of test bombs of approximately similar size and at equivalent heights. Fortunately for this study, it turned out that within a three-foot deviation of horizontal dimensions, a large two-story house, a middle-sized one-story house, and a small one-story house represented 90% of all Japanese houses in both Nagasaki and Hiroshima. In 1957 and again in 1958, the experiments were conducted and the results applied house by house and person by person to the cohort under study. In a city with such closely packed houses not only did the precise location of each person in the cohort study have to be determined, but the nature and configuration of intervening houses had to be taken into account. Needless to say, this was a massive undertaking. Text-figure 1 illustrates a typical work plan, with the street map of the locale at the top, the ground floor plans of the house next, finally a schematic of the intervening house next door, and the subject standing in the location he or she remembered in his or her own home at the lower right. Note that the radiation, the source of which is identified by the two arrows, passes through the roof, an attic partition, a ceiling, part of a floor and the outer wall of the house next door, and the outer wall of the house with the subject. Lest the reader assume that such calculations are simple, it might be




TEXT-FIGURE 1—A typical schematic to calculate exposure. The arrows point toward the bomb. At the top is a map of the street with the houses under consideration. The middle diagram shows the floor plans of two adjacent houses. The bottom illustrates a cutaway diagram from which is calculated the radiation exposure for the figure at the lower right.

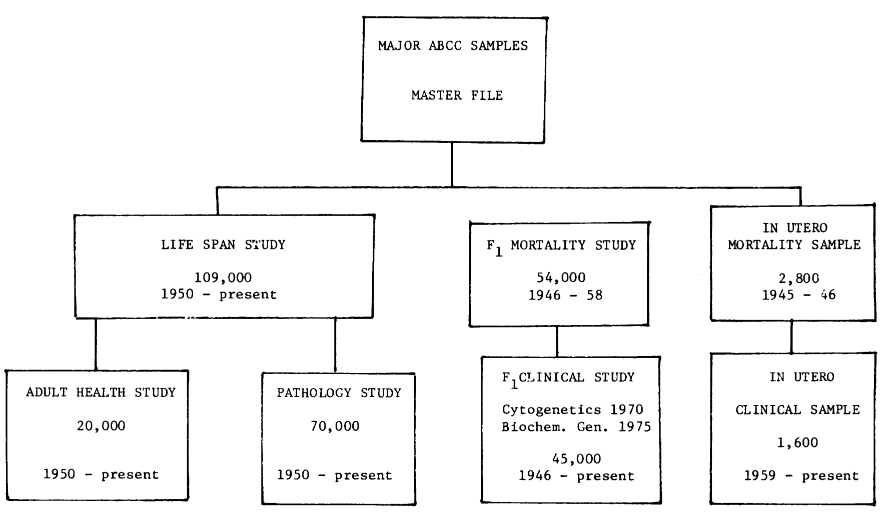
worth showing a typical equation used to calculate gamma radiation at Hiroshima:

$$\frac{D}{D_{air}} = 0.78 + 0.218e^{-SP} + 0.109e^{-FS} + 0.0498e^{-IFW} + 0.061FN - 0.00257SP - 0.00346FS$$

SP = slant penetration; FS = shield by neighboring house (in the example shown above the figure preceding this constant would require a separate and equally complex calculation); IFW = inside front wall; FN = floor.

The probable accuracy of such equations is ±20%, not too good but usable for large epidemiologic studies.

It is important to understand the way in which the population for the life span study was selected. (A schematic of the cohorts is shown in Text-figure 2.) The 1950 national census identified 195,000 as living in Nagasaki and Hiroshima. Every person was interviewed to determine where they were when the bomb exploded. Many were not in the city at the time or were vague about their location. One hundred nine thousand were finally selected, and the approximate radiation dosage has been established for 97%. Fifty-four thousand were within 2500 meters of the epicenter, and most received greater than 0.5 rad radiation; 28,000 were between 2500 and 10,000 meters, and most received less than 0.5 rad; while 27,000 had

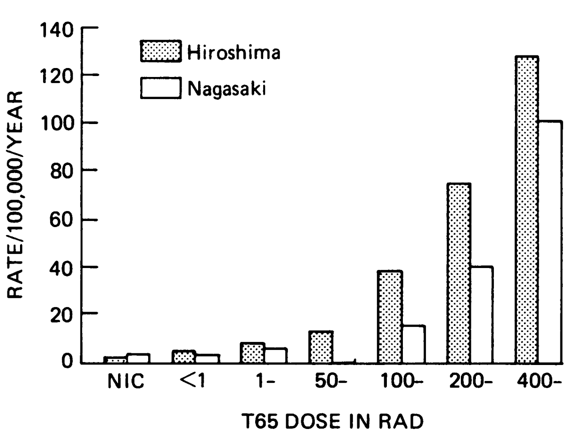



TEXT-FIGURE 2—The various population groups under study at the RERF.

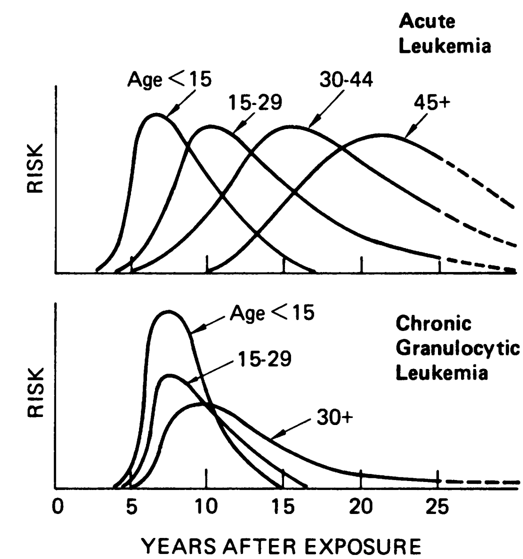
moved into the cities from other parts of Japan since the explosion and constituted the nonirradiated control group. Medical data on deaths are derived largely from death certificates and to a lesser extent from autopsy information. The subset in the Adult Health Study (20,000) has been followed closely by biennial medical examinations at the RERF. It should be emphasized that the epidemiologic studies were based upon lists created in 1950 and hence do not include data on the first five years following exposure, which would include the acute and semi-acute effects. Another significant point to bear in mind is that the studies concern a single exposure and may or may not be applicable to multiple exposures resulting in cumulative doses.

In the case of those directly radiated *in utero*, there was a reduction of head size with accompanying mental retardation in a statistically significant percentage. This was directly proportional to the amount of radiation and most marked when exposure occurred in the first trimester. In children exposed after birth, growth, as measured by average adult height, was diminished if the radiation was experienced before the age of 12.

Leukemia is of particular interest, since it is one of the most striking effects and its incidence rises sharply with increasing amounts of radiation received (Text-figure 3). Although acute lymphocytic, as well as acute and chronic myelogenous, leukemias were induced, there was no increase in chronic lymphocytic leukemia. The reasons for this striking discrepancy have not been determined but do at least suggest different origins. The latent period from exposure to the appearance of the acute leukemias lengthens as the age at which exposure occurred increases (Text-figure 4). In chronic myelogenous leukemias, on the other hand, this difference is not so manifest. It should also be noted that the risk declines toward the




TEXT-FIGURE 3—The combined incidence of leukemias at Hiroshima and Nagasaki. There is a striking dose-response relationship.




TEXT-FIGURE 4—A schematic depiction of the cumulative risk of acute and chronic leukemia over time. The latent period of acute, though not chronic, leukemia is age-dependent. Note, however, that the risk of chronic leukemia is dependent on age at exposure. Studies are now in progress to define the right-hand (*dotted*) portion of the curves. Preliminary data suggest that the acute leukemia's, like the chronic, may be returning to the baseline.

baseline with the passage of time. The extent of this decline is age-related, particularly in the case of acute leukemia. In other words, the incidence in the younger population returns more quickly to the baseline in the course of time than that in the older population. The incidence of leukemia, however, especially the acute form, continues to the present slightly above the baseline of the control population. Rates are higher at Hiroshima, presumably reflecting the neutron component of the bomb. For those under 15 years of age who were exposed to doses of 100 rads or more, the incidence is 20 times that of the control population.

Concerning solid tumors, children exposed to radiation have shown a minimum latent period of about 10–15 years. Since then, the incidence has climbed and continues to do so to the present. Cancer of the thyroid is especially prominent in women exposed before 10 years of age. Breast cancer continues to increase, and the relative risk is highest for women between 10 and 19 years of age at the time of radiation. Stomach cancer, which is surprisingly common in Japan generally, showed some increase at moderate radiation doses in Hiroshima but only at very high levels of radiation in Nagasaki. It is of interest that lung cancer was most noticeably increased if exposure occurred at the age of 50 or over. Other cancers that are beginning to emerge after a 15–20-year latent period are those of the urinary tract (especially bladder), salivary glands, and esophagus. Lymphomas also appear to be on the increase. Other tumors, such as those of bone, liver, or brain, have not been encountered in sufficient numbers to project clearly above the baseline, nor have increased deaths from cardiovascular or infectious diseases been detected. In other words, if one excludes the tumors cited, radiation, if survived through the acute phase, has not to date resulted in decreased life expectancy. Finally, deaths from tumors, while statistically significant, are not overwhelming in actual numbers. When last calculated in 1974 among the population of 54,000 who were exposed within 2500 meters, the norm was exceeded by 85 leukemia deaths and 100 deaths from the other forms of cancer discussed above.

Studies of the F-1 population, ie, 45,000 children conceived by mothers and/or fathers following exposure to radiation, have not shown chromosomal aberrations such as the translocations and dicentrics, which do occur in the survivors themselves and have persisted; nor has there been an increase in traditional congenital abnormalities, congenital metabolic diseases, detectable blood protein dyscrasias, or infant mortality. The sex ratio is not altered.

There are three critical areas demanding continued study as time recedes from the instant of exposure. The first concerns the solid tumors—their types and incidence—as more of the younger survivors approach ages at which tumors generally become more prevalent. A second problem of special interest is whether suppression of the immune mechanism, so prominent a feature in the acute stage, is reflected by subtle abnormalities later in life. So far all attempts to uncover such conditions have been unsuccessful. The third concerns the F-1 generation, which needs to be followed longer and with increasingly refined methods of analysis to detect any defects that may still be masked by a latent period. In the latter instance about 12,000 children of exposed parents and an equal number of control subjects are under intensive study. Blood samples are being obtained to examine 26 protein systems for electrophoretic variants. A centrifugal fast analyzer is also in use to detect kinetic variants of enzymes. On the basis of the pilot study, 2 or 3 rare variants should be encountered per 1000 protein examinations. These will require family studies, including other genetic markers, to determine whether the variant was transmitted and to assure parentage. It is anticipated that this study will continue for about 6 years, with 400 family studies per year.

Having contemplated the above, and in particular the statement that the absolute number of tumors is not overwhelming, one cannot but be drawn back inevitably to individuals and their families. More moving than the Peace Park in Hiroshima or the ruined building left as a monument or the museum built as a reminder of the horror is a very simple monument within the park. Standing alone and somewhat off to one side is a small concrete dome supported by columns. On the top of the dome is the statue of a young girl, who is holding a symbolic origami crane. It seems that this child, who had been exposed to the bomb at Hiroshima, developed leukemia. With the realization that she was dying, she was determined to fold a thousand paper cranes. She died before completing this number, but classmates finished them for her and a memorial was built. To this day, not only from Hiroshima and Nagasaki but from other parts of Japan as well, children with leukemia fold similar cranes, and these are hung in countless numbers under the dome. The Japanese people have discovered, just as we are discovering now, that leukemia knows no one cause and that in a single, tragic acquisition radiation cannot be ruled out. Neither, of course, can it be ruled in.

## Acknowledgments

I am grateful to Seymour Jablon of ALS for his useful advice and to Iwao Moriyama for his unpublished review "The Delayed Effects of Radiation Exposure Among A-Bomb Survivors." In addition, helpful information was obtained from *Ichiban* (*Radiation Dosimetry*), by John A. Auxier (published by the Energy Research and Development Administration) and from *Effects of Nuclear Weapons*, by S. Glasstone and P. J. Dolan (published by the Department of Defense and the Department of Energy). I should also like to acknowledge the *Atomic Bomb Casualty Commission (1947–1975) General Report* (published by RERF), and *RERF Technical Report #8, Mortality Experience of Atomic Bomb Survivors 1950–1974*, as well as numerous individual studies made available to me. The quotations of Dr. Cannan were taken from the *News Report* of the National Academy of Sciences, Vol XII, 1962, pages 1–7.

The following are general reviews of the data.

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*[Illustrations follow]*

**Figure 1**—A building 0.4 mile from ground zero at Hiroshima. The walls were constructed of reinforced concrete.

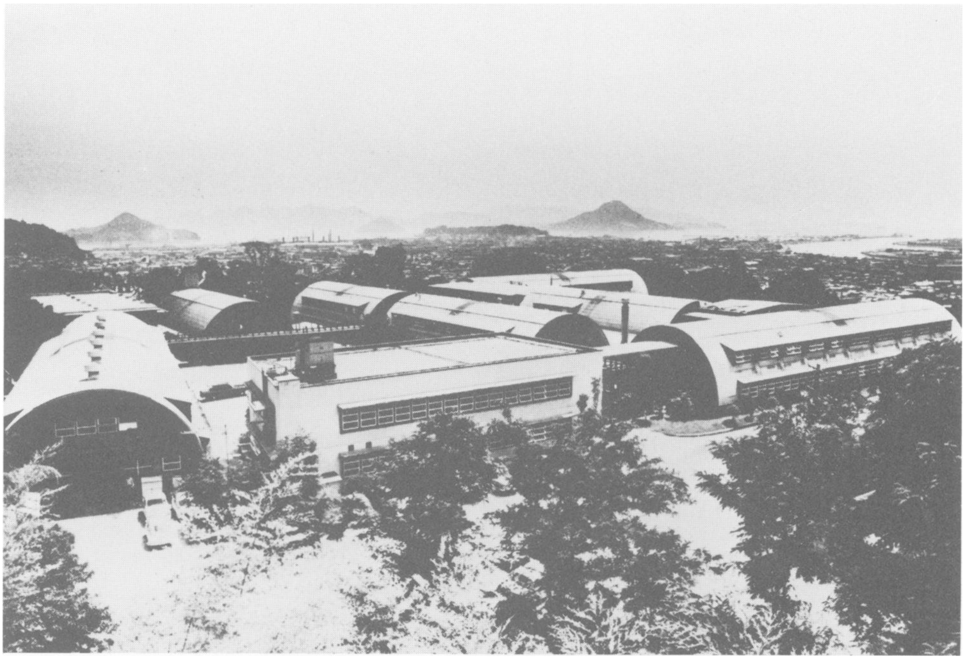


**Figure 2**—The RERF in the park at Hiroshima. The city and harbor lie below in the background. **Figure 3**—Japanese houses constructed at an atomic bomb test site. A variety of monitors recorded the radiation within houses at varying distances from ground zero.