

energy in comprehending their full significance. And beyond Hiroshima, these same impediments tragically block and distort our perceptions of the general consequences of nuclear weapons.

This volume, detailing the human tragedy at Hiroshima and Nagasaki and warning of the devastation that would result from a modern nuclear war, has been designed to help the reader overcome this resistance. Only those who permit themselves to confront the reality of nuclear weapons effects, past or future, can begin to grasp the danger we now face. Human survival may well depend on this ability.

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Acute Medical Effects at Hiroshima and Nagasaki

Takeshi Ohkita, M.D.

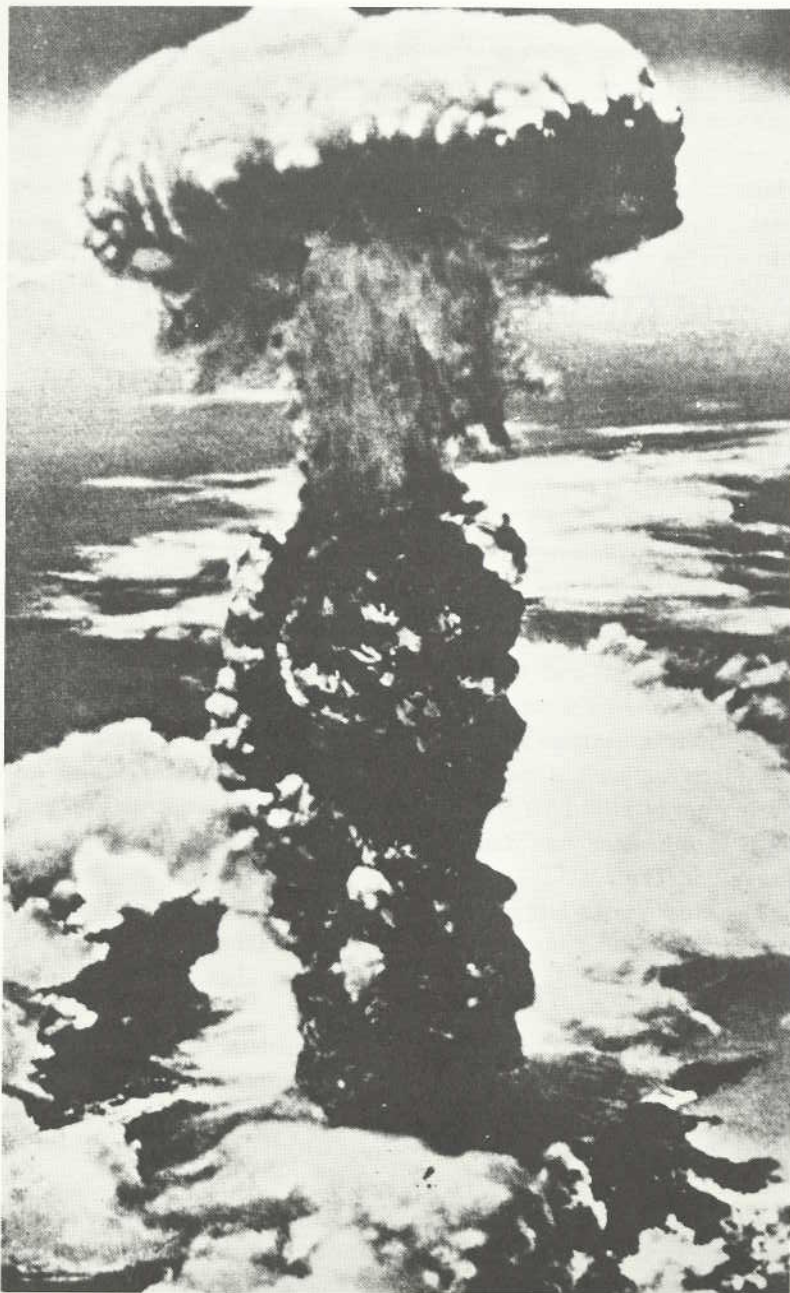
Modern science and technology have brought us many hopes and dreams. At the same time, they have caused much anxiety. From their sufferings since the atomic bombings in August 1945, the Japanese people recognize that the day has come when nuclear energy could be the weapon of ultimate destruction. Human intelligence has discovered something that is a cause for grave concern.

The clear marks left on the somatic cells of human bodies have not disappeared after more than 35 years. They are still causing various disturbances, which you will read about in the following pages.

I believe that we, as doctors and scientists, once again must realize the importance of our responsibilities. Together we must gather our wisdom and intelligence to abolish nuclear weapons from the face of the earth.

The acute effects of the Hiroshima and Nagasaki atomic bombs are summarized here, based on documentary records. Acute injuries caused by the atomic bombs are classified as thermal, mechan-

Adapted from "Review of Thirty Years' Study of Hiroshima and Nagasaki Atomic Bomb Survivors," *Journal of Radiation Research*, Supplement, 49-66, 1975. The photographs have been added.



Nagasaki, August 9, 1945, three minutes after the bombing. The smoke column has reached 20,000 feet. (Hiroshima-Nagasaki Publishing Committee, U.S. Army returned materials.)

ical, and radiation injuries. Combinations of these were most common. Many people died from the immediate effects of blast and burns, but individuals often succumbed to trauma or burns before the radiation syndrome developed. Many more would have died from irradiation, had they been saved from the effects of trauma or burns. Nearly all who died within ten weeks had signs suggestive of radiation injuries. Remarkable variation in sensitivity of body tissues to ionizing radiation was apparent. Radiation-induced bone marrow depletion was the most critical damage leading to death. In these instances, lowered numbers of white blood cells and platelets and subsequent infections and hemorrhagic tendencies were the main causes of death.

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Thermal Injuries

The intensity of the heat generated by the nuclear explosions in Japan is estimated to have been 3000–4000°C (5400–7200°F) at ground level near the hypocenters. Its duration was exceedingly short—0.5 to 1 second. The heat markedly dissipated with increasing distances from the hypocenters, but there was evidence that it was more than 573°C (1030°F) at distances of 1000 to 1100 meters (3200–3610 feet) and 1600 meters (5250 feet) from the hypocenters in Hiroshima and Nagasaki, respectively.

Thermal radiation causes burns directly, or indirectly from fires started by the flash. Direct burns are often called “flash burns,” since they are produced by the flash of thermal radiation from the fireball. Everyone exposed unshielded within 4 kilometers (2.5 miles) of the hypocenters (ground zero) probably received burns of some degree. Those beneath the burst were burned to death. In addition, persons in buildings close to the hypocenters might have been burned by hot gases and dust entering the structures, even though they were adequately shielded from direct thermal radiation. Severe third-degree burns with charring and skin death were commonly observed among people who were in the open within 1 kilometer (.6 mile) of the hypocenters.

Flash burns have also been termed “profile burns” since the lesions occur on the unshielded parts of the body exposed in a direct line with the origin of the thermal radiation. They were usually restricted to one side of the body and were sharply out-



Charred boy 700 meters from the hypocenter, Nagasaki. (Yosuke Yamahata, Hiroshima-Nagasaki Publishing Committee.)



Woman with severely burned back, Hiroshima, August 7, 1945. (Masayoshi Onuka, Hiroshima-Nagasaki Publishing Committee.)

lined. At the times of the bombings, hot weather prevailed. Most people wore short-sleeved shirts without coats. The effects of radiant heat were enhanced on the bare skin since clothing was protective to a variable degree, depending on its quality and color and the intensity of the heat.

Indirect burns, referred to as "flame burns," are identical with skin burns caused by fire. They may involve any or all parts of the body and tend to penetrate much deeper than do "flash burns." There were no essential differences in the healing processes of these two types of burns.

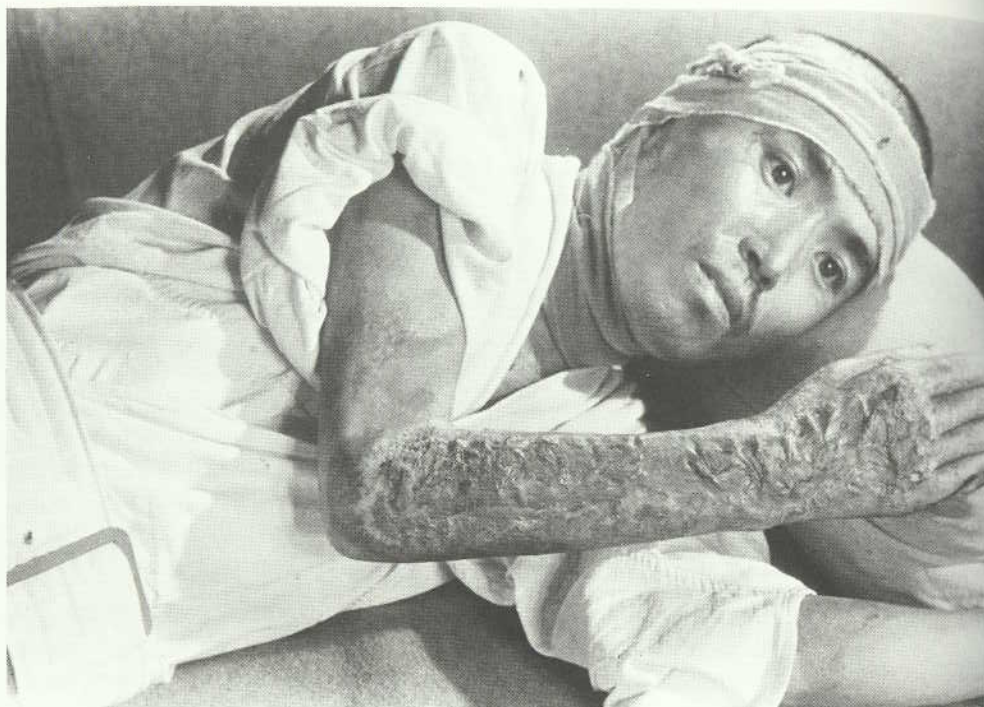
The frequency of burn injuries was exceptionally high. Burns seem to have been the major cause of death on the days of the bombings, but their relative proportion among all deaths is unknown. Many who were injured by the blasts were unable to escape and died in the fires. Flash and flame burns were often combined—some people were burned when their clothes were ignited by the flash of heat. Burns occurred under clothing at least as far as 2.5 kilometers (1.5 miles) from the hypocenters. The burns of those who survived, however, were largely flash burns. The incidence of flame burns appears to have been very small, constituting no more than 5 percent of the total burns.

All those in the open air without appreciable protection received severe burns within 1.5 kilometers of the hypocenters; moderate but fatal burns within 2.5 kilometers; and mild burns at distances of 3 to 4 kilometers from the hypocenters. As shown in Table 1, the incidence of burns in Hiroshima was nearly 100 percent among unshielded survivors at distances up to 2.5 kilometers, beyond which it fell rapidly. Burns were most frequent in persons outdoors and unshielded, considerably less frequent in

Parents, half crazy with grief, searched for their children. Husbands looked for their wives, and children for their parents. One poor woman, insane with anxiety, walked aimlessly here and there through the hospital calling her child's name.

M. Hachiya, M.D.

Hiroshima Diary: The Journal of a Japanese Physician,
August 6–September 30, 1945



Flash burns at Hiroshima, 2 kilometers from the hypocenter. This man was wearing short sleeves when the bomb exploded. He had a skin graft, taken from his hip, on his right hand. October 2, 1945. (Shunkichi Kikuchi, Hiroshima-Nagasaki Publishing Committee.)

those outdoors and shielded, and least among those who were indoors. There was little difference in the incidence of burns among those in concrete buildings versus those in Japanese-style houses.

The thermal energy was estimated to have been somewhat higher in Nagasaki, but the prevalence of burns was much lower. The overall incidence of flash burns in Nagasaki by distance from the hypocenter was similar to that of Hiroshima. A few second-degree burns with reddening of skin and blistering were recorded at distances from the hypocenters of 3.3 kilometers in Hiroshima and 3.1 kilometers in Nagasaki. No flash burns were reported beyond 4 kilometers in Hiroshima; whereas, in Nagasaki, about 3 percent of the persons exposed at 4 to 5 kilometers were reported to have received first-degree flash burns. The influence of shielding on the incidence of burns is clearly demon-

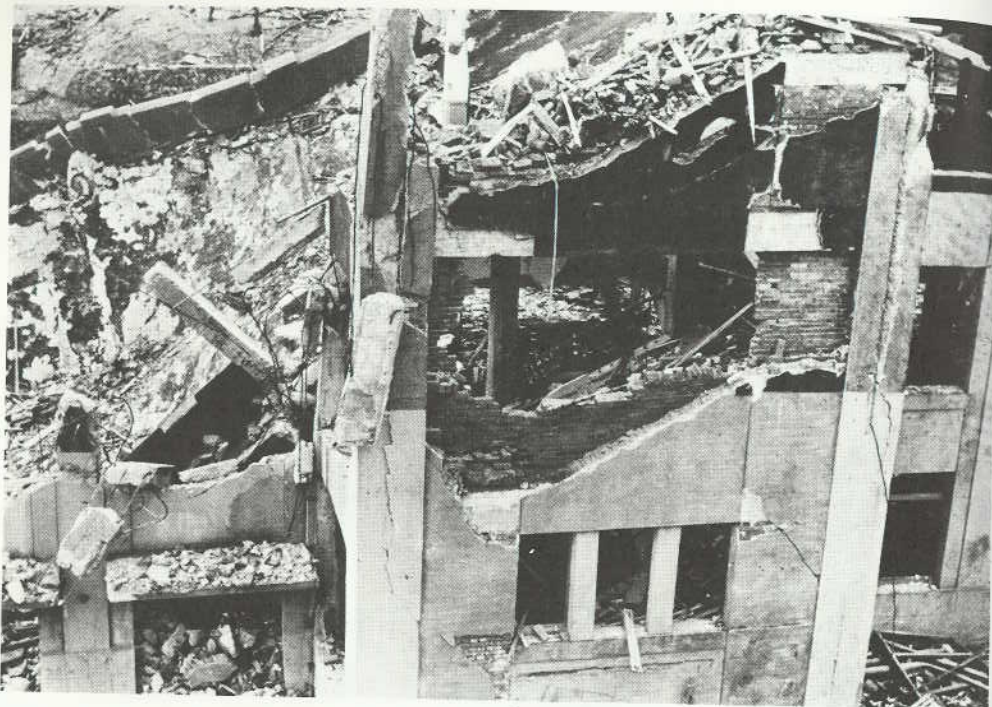
Table 1. Burns by distance and shielding in individuals living 60 days after the bombing, Hiroshima.

Distance from Hypocenter (km)	Shielding Conditions			Total Burns by Degree (%)		
	Outdoors Unshielded	Outdoors Shielded	Indoors			
	Cases with Burns/ Number Investigated (%)			First	Second	Third
0-0.5		2/3 (66.6)	3/24 (12.5)	6.2	52.7	41.1
0.6-1.0	22/22 (100.0)	34/68 (50.0)	33/210 (15.7)			
1.1-1.5	172/172 (100.0)	50/144 (34.7)	105/631 (16.6)			
1.6-2.0	518/528 (98.1)	64/176 (36.3)	135/770 (17.5)			
2.1-2.5	439/443 (99.0)	69/150 (46.0)	50/563 (8.8)			
2.6-3.0	98/124 (79.0)	19/94 (20.2)	23/284 (8.0)			
3.1-3.5	33/85 (38.8)	2/58 (3.4)	6/230 (2.6)			
3.6-4.0	4/40 (10.0)	0/12	0/102	Total of all conditions		
Total	1286/1414 (90.9)	240/705 (34.0)	355/2814 (12.6)	1881/4933 (38.1)		

Source: T. Kajitani and S. Hatano in *Collection of the Reports*, 1953; and *Report of the Joint Commission*, 1951.

strated from the data in Table 1. People inside buildings were burned only when the rays could reach them through doors and windows.

The incidence of burns was low up to 1.5 kilometers from the hypocenters due to the high mortality in this group. Survivors within this distance were probably partially shielded against radiant heat. Such a selective factor could account for the lower incidence of burns among survivors in an area where they otherwise

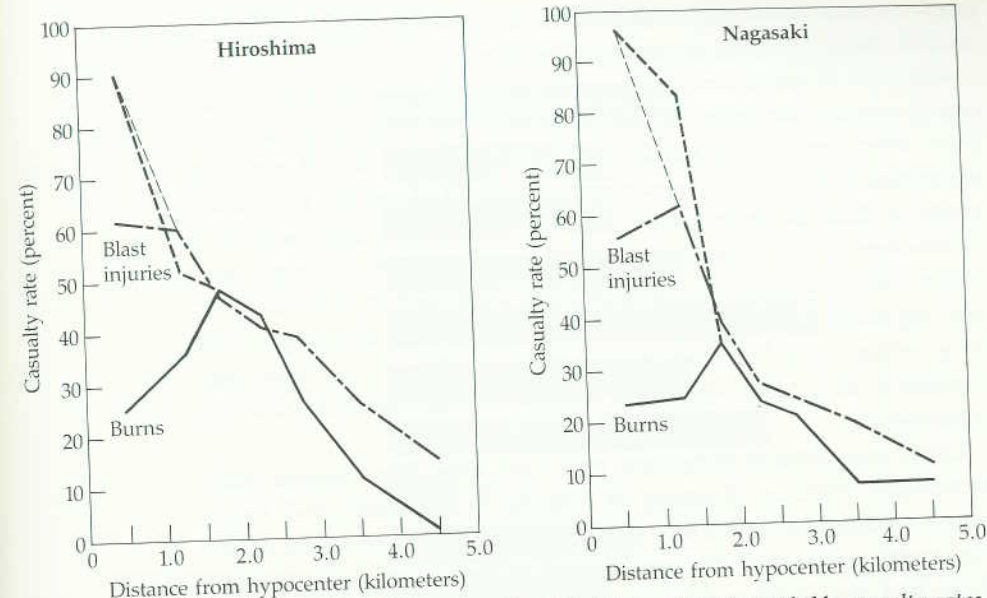


Collapsed stairways trapped students at the Shiroyama Elementary School in Nagasaki.
(Hiroshima-Nagasaki Publishing Committee, U.S. Army returned materials.)

could be expected to have been fatal. After the healing of severe burns, overgrowth of scar tissue was frequently observed, especially among survivors who were burned within 2.5 kilometers from the hypocenters [see Chapter 8]. Appreciable regression of protruding scars had occurred in most cases by 1952.

Mechanical (Blast) Injuries

The blast pressures generated by the Hiroshima and Nagasaki atomic bombs at ground zero are estimated to have been 4.5–6.7 and 6–8 tons per square meter, respectively. The blasts consisted of two phases: compression and suction. The duration of the compression phase is estimated to have been approximately one-half to one second. Mechanical injuries resulting from the blasts were direct and indirect, mostly the latter, and were chiefly caused by collapsing buildings and flying debris.



Incidence of blast injuries and burns by distance. The dotted lines show the probable casualty rates in the innermost zones, assuming that all those who died were injured by blast and radiant heat.
(After Oughterson and Warren, 1956.)

So far, there have been no reliably established deaths attributable to direct blast effects. [Editors' note: That is, resulting from the direct blast pressure on human bodies alone, exclusive of collisions between bodies and various objects.] Indirectly, the blasts caused many instantaneous deaths. The incidence of indirect mechanical injuries among survivors is shown in the figure above. Blast injuries occurred mostly among people in concrete buildings, somewhat less among those in Japanese-style houses, less outdoors with shielding, and least frequently among those outdoors without shielding—exactly the reverse order from that of burns. This also suggests that buildings and walls offered more risk than protection, especially at close range.

Mechanical injuries of survivors were of all degrees, from minor scratches to severe lacerations and compound fractures. The most common injury was laceration by small glass fragments. Fractures were infrequent, but many who did not survive probably had severe fractures. With the extreme scarcity of medical care soon after the bombings and because of leukopenias (lowered white blood cell counts) due to ionizing radiation, minor lac-

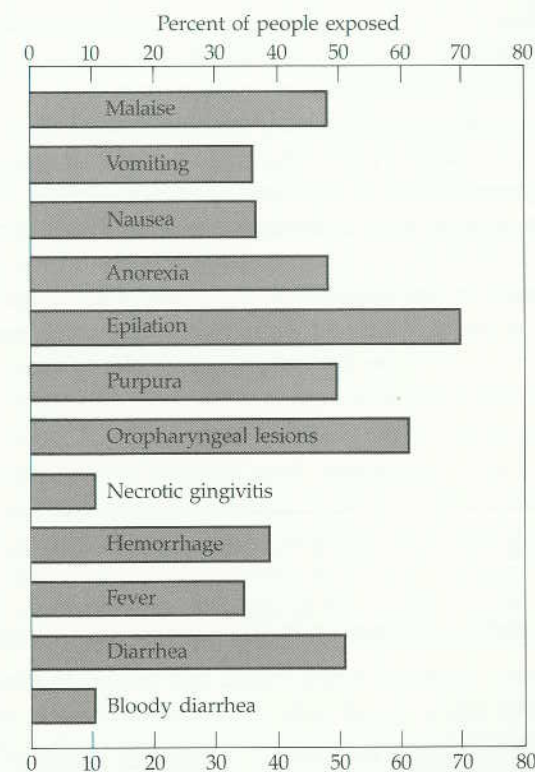
erations and abrasions, which ordinarily would have promptly healed, often resulted in severe infections.

Rupture of eardrums was considered evidence of direct blast injury among survivors. At the Ninoshima Hospital in Hiroshima, soon after the atomic bomb, only 8 (2 percent) of 371 patients examined had ruptured eardrums, though 19 of the 371 were temporarily deaf. Seventy-six percent of the 371 had been within 2 kilometers of the hypocenter. Eight percent of 198 Nagasaki survivors exposed within 1 kilometer and examined in October 1945 had ruptured eardrums. Among survivors in both cities surveyed by questionnaire, less than 1 percent at any distance reported this condition, and none who were located farther than 3 kilometers reported it.

Other less-defined symptoms may have been blast-related, such as vertigo, tinnitus (buzzing or ringing in the ears), and headache—without evidence of trauma. About 15 percent of the survivors surveyed in each city complained of these symptoms. Most of them had been within 2.5 kilometers. Loss of consciousness was also reported, but most cases of transitory unconsciousness were more likely caused by violent displacement, such as being thrown to the ground, rather than by direct blast. Regarding later effects of mechanical injuries, no data for the precise number of disabled survivors are available.

Radiation Injuries

Though the Hiroshima and Nagasaki atomic bombs afforded the first opportunity to observe the effects of massive ionizing radiation exposure in humans, little is known of the severe radiation injuries that caused immediate deaths, because these cases were not autopsied. In addition, the high rates of deaths and injuries during the first few days after the atomic bombs precluded an accurate statistical evaluation of the effects of ionizing radiation. The symptoms among survivors with radiation injuries and alive three or more weeks after the bombs will be briefly presented. Bear in mind that definitive criteria for diagnosing radiation injuries and their severity are difficult to establish because such injuries (e.g., leukopenia and thrombocytopenia) may not have been immediately manifest in many cases, and some symptoms may have been attributed to or complicated by causes (e.g., burns, mechanical injuries, poor sanitary conditions) other than radiation.



Prevalence of symptoms and signs within 1000 meters of the hypocenter at Hiroshima. The air dose at 1000 meters was 447 rads. Diarrhea includes bloody diarrhea. (After the Report of the Joint Commission, 1951.)

Clinical Symptoms and Signs of Radiation Injuries

The prevalence of the main clinical symptoms and signs in those located within 1.0 kilometer of the hypocenter in Hiroshima is shown in the figure above. These survivors were undoubtedly exposed to large doses of ionizing radiation except for a few who were heavily shielded, as by bomb shelters. Epilation (the loss of hair), purpura (hemorrhaging into the skin or internal organs), and oropharyngeal ulceration (punched-out sores in the back of the throat) were the most frequent signs. The first two were usually in combination and are considered the most reliable diagnostic signs of radiation injury. Oropharyngeal ulceration was not as specific for radiation injury.

Chronologically, symptoms and signs can be grouped as fol-

lows: Phase I, the prodromal (the early manifestations of an illness) radiation syndrome, usually of one or more days' duration and consisting of prostration and gastrointestinal symptoms, including nausea, vomiting, and anorexia (loss of appetite); Phase II, a period of relative well-being whose duration is variable but inversely proportional to the exposure dose; Phase III, a feverish period of several weeks' duration, with epilation, oropharyngeal ulceration, infection, hemorrhaging, and diarrhea; and Phase IV, either death or prolonged convalescence with eventual recovery.

In many cases, the second phase of temporary well-being was not observed. In those severely injured, the feverish phase often began between the fifth and seventh days, but sometimes as early

hematological pertaining to the blood and blood-forming tissues.

hematopoietic pertaining to the formation of blood cells.

leukopenia lowered white blood cell count. Normal values are 5000–10,000 white blood cells per cubic millimeter of blood.

prodromal radiation syndrome Phase I of radiation illness—the early manifestations of radiation injury.

rad unit of radiation; an acute exposure of 450 rads will be lethal for approximately 50 percent of a healthy adult population, more than 600 rads will be lethal for virtually 100 percent.

Relative Biological Effectiveness (RBE) for a given type and energy of radiation, the dose of gamma rays necessary to produce the same biological effect as a unit dose of the radiation in question. The RBE of gamma rays, the reference, is 1; beta rays are also roughly 1; thermal neutrons are 5; fast neutrons 10; and alpha particles 20. Therefore, 1 rad of fast neutrons produces the same biological effect in humans (rem) as 10 rads of gamma rays.

rem (roentgen-equivalent-man) amount of radiation that, when absorbed into the body, produces the same biological effect as 1 roentgen (or rad) of gamma rays.

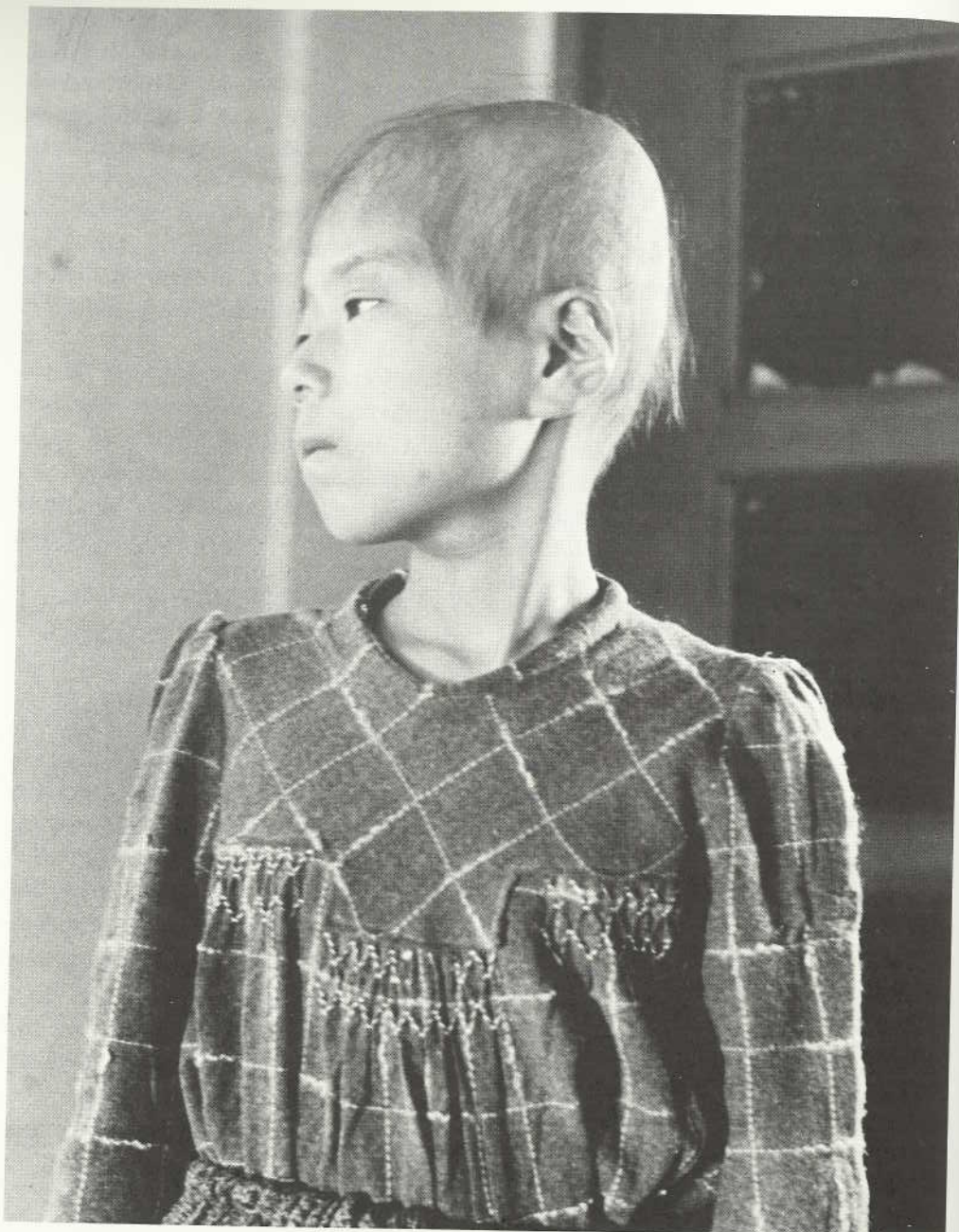
thrombocytopenia lowered blood platelet count. Normal values are 200,000–500,000 platelets per cubic millimeter of blood.

as the third—with severe diarrhea as its most prominent manifestation—and continued until death. In the less severely injured, epilation about two weeks after exposure—initiating the feverish phase—was soon followed by purpura and oropharyngeal lesions. Despite marked individual variation, the severity of manifestations depended on the radiation exposure. The severely exposed (as great as 450 rads or more) usually died within two weeks. Less severely but fatally exposed died, as a rule, before the end of the sixth or eighth week after exposure. Additional comments about the symptoms and signs of radiation injuries follow.

Nausea and Vomiting. Though there were many causes other than ionizing radiation for nausea and vomiting, these are well-established initial signs of radiation sickness. Distance correlated closely with vomiting on the first day; less so, later. In the more heavily exposed, these signs usually persisted, frequently lasting several days, and in some throughout the entire course of illness. The presence of burns had no influence on nausea and vomiting.

Epilation. Epilation is considered one of the specific signs of radiation injury. It began one to four weeks post-exposure, but the peak occurred in the second and the third weeks. Hair fell out in bunches on combing or gentle plucking. Onset correlated roughly with the exposure dose as estimated from distances and shielding. Epilation was an easily recognized sign following a latent period and sometimes clinically heralding the onset of radiation injuries. Survivors with early epilation usually had more severe syndromes. The extent of epilation did not correlate with prognosis. The scalp was the area most commonly involved by epilation; axillary and pubic hair were little affected. By the 12th to 14th weeks there was regrowth of hair; no permanent epilation was noted.

Purpura. Purpura was recognized as early as the third day and the peak was 20 to 30 days after the atomic bombs in both cities. As with epilation, the prevalence of purpura correlated closely with dose. A sharp drop in purpura was observed among survivors exposed beyond 1.5 kilometers (1 mile). The reported preva-



This girl has lost her hair. She was at home in a wooden house about 2 kilometers from the hypocenter. Hiroshima, October 6, 1945. (Shunkichi Kikuchi, Hiroshima-Nagasaki Publishing Committee.)

lence of purpura was undoubtedly lower than the actual because, if minimal, it frequently was not recorded.

Other Symptoms. Oropharyngeal lesions; hemorrhagic manifestations including nosebleed, uterine bleeding, and hemorrhages from the mouth, rectum, and urinary tract; and fever with or without apparent infection were undoubtedly signs related to radiation damage of the hematopoietic and gastrointestinal systems. Diarrhea was a common sign suggestive of radiation injury. However, there were many other causes for diarrhea because of conditions extant after the atomic bombs.

Outline of Clinical Course and Prognosis

It has been estimated that about 64,000 Hiroshima and 39,000 Nagasaki civilians were either killed immediately or died within about two months. Of these, about 50 percent died within 6 days and 96 percent died within 20 days. Since multiple injuries were common, the true causes of death were in many cases unknown, especially of those who died within three weeks. However, nearly all who died within three weeks had signs suggestive of radiation injuries. Furthermore, radiation injuries, with burns and other trauma, undoubtedly contributed to the total lethal effects.

The prodromal radiation syndrome was most marked in the very severely exposed, most dying within two weeks and having blood-cell abnormalities as well. Others dying 30 days after the bombs had milder prodromal syndromes.

In those less severely exposed, coincidental with the leukopenia and thrombocytopenia, signs of infections and hemorrhagic tendencies followed next in order and lasted from three to six weeks. The clinical courses and prognoses of survivors varied individually because of the diversity of combined thermal and blast injuries and various conditions of irradiation. The usual clinical course and severity of signs and symptoms observed in the first three weeks in each category are shown in Table 2, though there must have been considerable overlap. Dose-effect relations for humans are not precisely known, even for truly homogeneous whole-body exposure. However, comparison of published analyses with the categories of severity of exposure in Table 2 suggests exposure doses of 450 to 600 or more rads for Group I; 300 to 450

Table 2. Atomic bomb survivors by clinical symptoms and signs of radiation injuries. (##) (++) (+) and (±) connote grade of symptoms and signs in order of decreasing severity.

Degree of Severity*	First Week	Second Week	Third Week	Approximate Mortality and Time of Death
Very severe (Group I)	Nausea and vomiting (##) Fever, apathy, delirium, diarrhea (##) Oropharyngeal lesions (+)** Leukopenia (##)	Fever (++) Emaciation Leukopenia (##) Anemia Hemorrhagic diathesis (±) [†] Epilation (±)		100% First and second weeks
Severe (Group II)	Nausea and vomiting (++) Anorexia Fatigue	Fever (++) Leukopenia (+) Anemia (±)	Anorexia, emaciation, fever, diarrhea, epilation (##) Oropharyngeal lesions (##) Hemorrhagic diathesis (##) Leukopenia (##) Anemia (++)	50% Third to sixth weeks
Moderately severe (Group III)	Gastrointestinal [‡] syndrome (++)	Leukopenia (+)	Anorexia, emaciation, fever, diarrhea, epilation (± ~ ++) Oropharyngeal lesions (± ~ ++) Hemorrhagic diathesis (± ~ ++) Leukopenia (++) Anemia (+)	Less than 10% Sixth week or later
Mild (Group IV)	Gastrointestinal syndrome (±)	Leukopenia (+)	Fever (±) Epilation (±) Oropharyngeal lesions (±) Hemorrhagic diathesis (±) Leukopenia (±)	None

*This classification is presented only as an orientation, and there must have been considerable overlap in each category. These descriptive terms were used by the Joint Commission for the Investigation of the Atomic Bomb in Japan.

**These lesions (ulcerations) occurred on all mucous membrane surfaces but were more prevalent in lymphoid areas. The tonsil, pharynx, larynx, nasal passages, and tongue were frequently involved.

[†]Hemorrhagic diathesis is the tendency to spontaneous bleeding or bleeding from a trivial trauma.

[‡]Gastrointestinal syndrome includes nausea, vomiting, anorexia, and diarrhea.

Table 3. Civilian casualties and mortality for Hiroshima and Nagasaki. Population figures have been rounded off to the nearest thousand.

	Hiroshima	Nagasaki
Total casualties	136,000	64,000
Died first day	45,000	22,000
Died after first day	19,000*	17,000
Dead in four months	64,000**	39,000
Living injured first day	91,000	42,000
Surviving casualties	72,000	25,000
Uninjured	119,000	110,000

*Of this number, 86.5 percent died within 20 days.

**Of this number, 96.0 percent died within 20 days.

Source: Oughterson and Warren, 1956.

rads for Group II; 200 to 300 rads for Group III; and 100 to 200 rads for Group IV. Statistical analyses of correlation between mortality rates of survivors and distances from the hypocenters showed that 50 percent mortality among the lightly shielded was observed at 1.2 kilometers in both cities.

Numbers of Casualties

Hiroshima is built on the delta of the Ota River. The atomic bomb burst nearly over the center of the city. Nagasaki is located at the head of a long, narrow bay, is surrounded by hills, and extends along both sides of the bay and up into two valleys. The bomb exploded over one of these valleys, and the effects of the bomb were largely confined to this one valley. In Hiroshima, approximately 60 percent of the population was within 2000 meters of the hypocenter; in Nagasaki, only 30 percent was so situated. These differences influenced the effects in the two cities, loss of life and physical destruction having been greater in Hiroshima than in Nagasaki.

There is continuing controversy regarding the numbers of persons killed by these bombs. The numbers of civilian casualties estimated by the Joint Commission are shown in Table 3. These numbers do not include military casualties, nor survivors with late effects. No data concerning military casualties, which must have been large in Hiroshima, are available.

The numbers of persons among the survivors with burns, blast, or ionizing radiation injuries, or a combination thereof, were estimated by the Joint Commission. For Hiroshima, these victims numbered approximately 60,000 with burns, 78,000 with blast injuries, and 35,000 with radiation injuries. For Nagasaki, there were an estimated 41,000 burns, 45,000 blast injuries, and 22,000 radiation injuries. These may have occurred in combination.

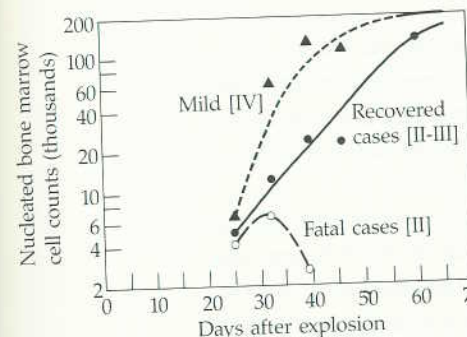
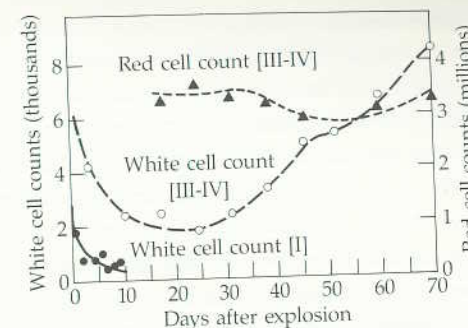
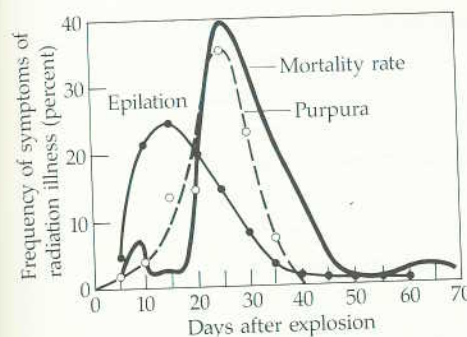
Atomic Bomb Radiation in the Acute Stage

Background

The most conspicuous prodromal radiation syndrome includes nausea, vomiting, diarrhea, fever, hypotensive shock (shock associated with lowered blood pressure), and lassitude. The subsequent courses of those having the acute radiation syndrome is predictable by the severity and duration of the early symptoms and signs. This initial symptom complex has long been known as "radiation sickness," common in patients receiving radiation therapy, but it is only the initial syndrome. To avoid confusion with subsequent acute radiation symptoms such as hematopoietic depletion (a shutting down of the blood-forming system), the term "prodromal radiation syndrome" is more appropriate than "radiation sickness."

As to its severity, marked individual variability is involved. Recent studies indicate that with a sufficiently large single dose of deeply penetrating ionizing radiation, individual variability is minimized, and nearly all exposed individuals develop all prodromal signs. With a few thousand rads, all individuals can be expected to have the syndrome within 15 minutes, and it may persist for several days until their death.

The prodromal syndrome can be produced by irradiating the abdomen, thorax, or head. Epigastric (the upper middle area of the abdomen) irradiation elicits the response with the least dose, while irradiation of the extremities is not effective. Shielding the abdomen with lead during total body irradiation can protect against this response. These results also suggest that the autonomic nervous system plays an important role in the prodromal syndrome. Immediate diarrhea, fever, and hypotension seem to signify supralethal exposure.



Severity of clinical symptoms of radiation injuries
Group I: Very severe
Group II: Severe
Group III: Moderately severe
Group IV: Mild

Mortality rate, clinical signs of radiation injuries, and hematopoietic cell counts of survivors during the first ten weeks after the Hiroshima atomic bomb.

Hematological Findings in the Acute Stage

Bone marrow depletion by irradiation is the most critical damage leading to death. The clinical course following atomic bomb radiation injuries, mortality, and some hematological data are shown in the figure above. Data in this figure were compiled from all sources, primarily in Hiroshima. The upper part of this figure shows the Hiroshima mortality curve to be bimodal, the first small peak having occurred eight or nine days after exposure. By historical classification, the term "gastrointestinal death" due to total body irradiation was at times proposed for these early deaths. These victims who died early had extensive bone marrow damage, manifested by leukopenia and thrombocytopenia. However, "gastrointestinal death" is now suggested to be a rapid form of hematopoietic death rather than as originally assumed, "death resulting from gastrointestinal damage."

The second mortality peak occurred between the 20th and 40th days in both cities. The death rates of survivors diminished markedly thereafter. The figure shows that the frequency of purpura correlated with the second mortality peak. Fever (not shown in the figure) was highest in frequency between the 20th and 30th days. Conversely, counts of nucleated cells of the bone marrow and of circulating white blood cells were profoundly reduced during the same period. Epilation was a first warning symptom of the second critical phase.

Results clearly indicate that the sequence of events in heavily irradiated people was as follows: severe, persistent bone marrow depletion causing a decrease in the number of all blood cells, leading to infections, oropharyngeal lesions, fever, a hemorrhagic tendency, and death. Denuding of the villi (projections that serve as sites for absorption of nutrients) of the intestinal epithelium may play a significant role.

In spite of early recognition of the syndrome of radiation injury by Japanese doctors, few specimens of bone marrow were obtained during the first three weeks because the attending physicians were too busy to perform biopsies. Only two bone marrow specimens, the earliest, were obtained on the sixth day, from Hiroshima survivors exposed in a concrete building 250 meters from the hypocenter. Their nucleated cell counts were not recorded, but drastic reductions in numbers of bone marrow cells were apparent. Both patients had slight burns and their circulating white blood cells numbered only $300/\text{mm}^3$ (normal values are $5000\text{--}10,000/\text{mm}^3$). Their platelet counts were about one-third of normal and they died on the eighth and eleventh post-exposure days.

After the arrival of research teams from medical schools about four weeks after the bombs, physicians began recording bone marrow findings. The lowest portion of the figure on p. 87 shows the mean values of nucleated bone marrow cell counts demonstrating the regenerating processes of the bone marrow with time. At the fourth week, the average bone marrow cell count was very low in each group. Subsequently, among the cases in Group II who died within six weeks, there was no recovery until death. In cases who recovered (Groups II, III, and IV), low values were still evident at the seventh week, but gradual regenerating processes were seen after that, and their bone marrow cell counts reached normal levels. In those very severely injured cases, low white

blood cell counts progressed rapidly and counts were usually less than $500/\text{mm}^3$ between the fifth and twelfth days. In those who survived more than ten days, the greatest white blood cell count depression occurred between three and five weeks post-exposure. Depression of white blood cell counts from the third to fifth week was found to correlate with death and was concluded to be the best prognostic indicator.

A number of factors obscured the red blood cell counts of atomic bomb survivors, especially blood loss from wounds, dehydration by severe burns and by diarrhea, bone marrow depletion, hemorrhagic tendencies, and severe infections. In severely exposed cases (Group II), the red cell counts declined at a steady rate and their minimum values were reached at about the same time as those of white cell counts, the minimum of which, in many cases, coincided with death. There is no clear evidence, however, that the degree of anemia is useful in prognosis. In the moderately and mildly exposed cases (Groups III, IV), the lowest red cell counts and hemoglobin concentrations were observed from six to nine weeks after the bombs, and their mean values had not returned to normal, even by the twelfth week. This was supported by the low counts of regenerated young red blood cells that were obtained between eight and twelve weeks. More than 60 percent of these were less than normal.

Platelet counts soon after the bombing were recorded for only two of the very severely exposed Hiroshima cases, both of them six days after the bomb. The total platelets were $87,400/\text{mm}^3$ and $64,500/\text{mm}^3$ (normal counts: $200,000\text{--}500,000/\text{mm}^3$), and the patients died on the eighth and ninth days. Neither had skin purpura. Of 20 patients in Group I and dying within ten days, only 1 had cutaneous purpura. Purpura of the organs was frequently noted, however, in autopsy cases during the same period. In Groups II and III, the frequency of platelet counts of less than $25,000/\text{mm}^3$ was found in 83.3 percent of the fatal and 20.8 percent of the nonfatal cases. Thus, the severity of thrombocytopenia correlated directly with radiation dose and afforded a rough index of survival.

Laboratory data on hemostasis (the arrest of bleeding) and coagulation in the survivors were scarce, and none were obtained for those who received the highest doses because all of them died within two weeks of the bombs. In the severely exposed (Group

II), moderate prolongation of whole blood coagulation time was reported. Prolonged bleeding times were concomitant with the onset of hemorrhagic diathesis (tendency to spontaneous bleeding or bleeding from a trivial trauma), and their degrees were proportional to the decreases in platelet counts. As platelet counts approached normal levels, bleeding times became correspondingly shorter, and all had returned to normal by the ninth week post-exposure.

Recent studies have shown that, after the platelets, fibrinogen (a blood constituent critical to clot formation) is the next most radiosensitive clotting factor. Low coagulability with deficient clot formation, caused by qualitative changes in fibrinogen, is suspected to have occurred in the severely irradiated survivors. Increased capillary fragility is also responsible for post-radiation hemorrhage.

Space does not permit a detailed description of recovery of hematopoietic cells. In most survivors, blood values had reached normal by the end of the second year, but many instances of various blood abnormalities (i.e., anemia, eosinophilia (an abnormally large number of eosinophils—a type of white blood cell), leukopenia, thrombocytopenia, and capillary fragility) have all been reported, especially among the heavily irradiated survivors eight to eleven years after the atomic bombs.

Relative Biological Effectiveness of Atomic Bomb Neutrons

Mortality from ionizing radiation among survivors who were shielded, mainly by Japanese-style houses, was estimated by the Joint Commission using a population sampling method. The curves obtained reveal that mortality was 50 percent at a distance of 1.2 kilometers ($\frac{3}{4}$ mile) from the hypocenter in each city. The ratios of gamma to neutron dose to the survivors were very different in the two cities. According to the Atomic Bomb Casualty Commission estimates for air-dose values, in Hiroshima the radiation dose at 1.2 kilometers was about 154 rads, consisting of 95 rads of gamma rays and 59 rads of neutrons. In Nagasaki, the air-dose value at 1.2 kilometers was about 403 rads: 392 rads of gamma rays and 11 rads of neutrons. The Nagasaki neutron dose was so small that, for practical purposes, survivors at this distance can be considered to have received only gamma radiation. Thus,

the relative biological effectiveness (RBE) of atomic bomb neutrons at 1.2 kilometers for acute lethality can be calculated:

$$95 + (59 \times \text{RBE}) = 392$$
$$\text{RBE} \approx 5$$

Effects on Spermatogenesis

From 1.5 to 3 months after the explosion, semen of 131 Hiroshima atomic bomb survivors were examined. No abnormalities were found in the physical or chemical character of seminal fluid, indicating normal function of the prostate gland. However, good correlation between sperm count and exposure distance was noted. Sperm counts of less than $10 \times 10^6/\text{cc}$ semen were found mostly in proximally exposed survivors. (Normal sperm count is $20\text{--}60 \times 10^6/\text{cc}$; many authorities consider $20 \times 10^6/\text{cc}$ the lower limit of fertility.)

Low sperm counts were found in 42 (70 percent) of 60 persons exposed within 1.5 kilometers and in 18 (25 percent) of 71 exposed beyond this distance. Supportive of this were autopsy findings that as early as the fourth day after exposure, the testes of victims showed extensive death of the sperm germ cells. These were most marked in those who died early and had been within 1.5 kilometers of the hypocenter. High frequencies of morphological abnormalities and reduced sperm motility were also recorded in proximally exposed survivors. Nine months after exposure, sperm counts in 11 of 12 survivors exposed within 1.6 kilometers were less than $10 \times 10^6/\text{cc}$. Twenty-two months after the bomb, low sperm counts were still evident in 11 (41 percent) of 27 survivors exposed within 1.6 kilometers.

The next sperm counts in January 1959, 13.5 years after the bomb, confirmed 3 Hiroshima cases having an absence of sperm in seminal fluid. They were exposed within 1.3 kilometers from the hypocenter, and each had a clinical history of radiation injury in the acute stage. However, sperm counts of 10 survivors exposed within 1.6 kilometers and reexamined at this same time had all returned to normal. There was recovery of sperm motility and reduced numbers of abnormal forms.

Results obtained from study of nuclear accidents and the Bikini survivors show the same pattern of sperm count fluctuations. The

greatest depression was observed between the seventh and ninth months after exposure, and recovery, when possible, usually occurred by the end of the second year.

References

- Collection of the Reports on the Investigation of the Atomic Bomb Casualties.* 2 vol. 1953. Japan Society for the Promotion of Science. Tokyo: Maruzen.
- Guskova, A. K., and G. D. Baysogolov. 1971. "Radiation Sickness in Man." Translation series, AEC-tr-7401.
- Kajitani, T., and S. Hatano. 1953. "Medical Survey on Acute Effects of the Atomic Bomb in Hiroshima." In *Collection of the Reports of the Investigation of the Atomic Bomb Casualties*, vol. 1. Japan Society for the Promotion of Science. Tokyo: Maruzen.
- Oughterson, A. W., G. V. LeRoy, A. A. Liebow, E. C. Hammon, H. L. Bennett, J. D. Rosenbaum, and B. A. Schneider. 1951. *Medical Effects of Atomic Bombs: The Report of the Joint Commission for the Investigation of the Atomic Bomb in Japan.* 6 vol. Washington, D.C.: U.S. Atomic Energy Commission.
- Oughterson, A. W., and S. Warren, eds. 1956. *Medical Effects of the Atomic Bomb in Japan.* New York: McGraw-Hill.
- Warren, S., and J. Z. Bowers. 1950. "The Acute Radiation Syndrome in Man." *Annals of Internal Medicine*, 32:207-216.

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Delayed Medical Effects at Hiroshima and Nagasaki

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Soon after the end of World War II, the Japanese and United States governments sent teams to investigate the effects of the Hiroshima and Nagasaki atomic bombs. Although it was known in 1945 that ionizing radiation could induce mutations, cancers, and other deleterious effects in plants and experimental animals, little was known about how ionizing radiation from atomic bombs might affect the exposed survivors in the succeeding years.

The Atomic Bomb Casualty Commission (ABCC) was organized in 1946 under the direction of the National Research Council of the National Academy of Sciences in the United States, and in 1948 the National Institute of Health of the Japanese Ministry of Health and Welfare formally joined in its studies. The Research Institute for Nuclear Medicine and Biology was started at Hiroshima University in 1961, and the Atomic Diseases Institute at Nagasaki University in 1962. In 1975, the ABCC was dissolved and the Radiation Effects Research Foundation (RERF) replaced it as a joint enterprise of the Japanese and American governments, to continue the surveillance of the Hiroshima and Nagasaki atomic bomb survivors for long-term aftereffects.

In this report, a brief summary will be presented on the major points based on careful and painstaking studies carried out by many American and Japanese scientists. Table 1 gives the