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The United States Strategic Bombing Survey: The Effects of Atomic Bombs on Hiroshima and Nagasaki, June 30, 1946

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THE UNITED STATES STRATEGIC BOMBING SURVEY

THE EFFECTS OF ATOMIC BOMBS ON HIROSHIMA AND NAGASAKI

CHAIRMAN'S OFFICE

30 June 1946

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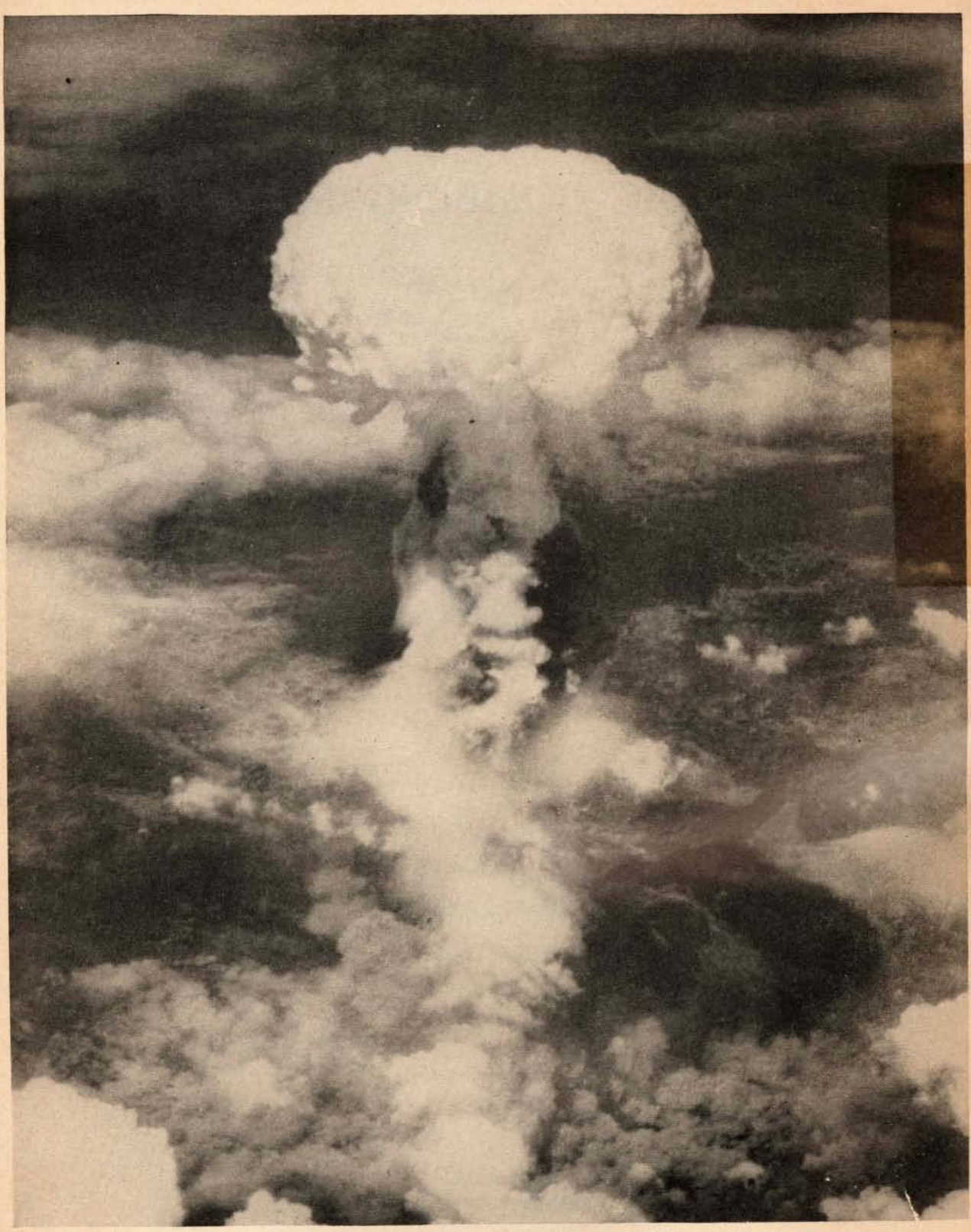


". . . the power of the atomic bomb is beyond belief . . ."
Nagasaki Prefecture Report

A. A. F. Photo

FOREWORD

The United States Strategic Bombing Survey was established by the Secretary of War on 3 November 1944, pursuant to a directive from the late President Roosevelt. Its mission was to conduct an impartial and expert study of the effects of our aerial attack on Germany, to be used in connection with air attacks on Japan and to establish a basis for evaluating the importance and potentialities of air power as an instrument of military strategy, for planning the future development of the United States armed forces, and for determining future economic policies with respect to the national defense. A summary report and some 200 supporting reports containing the findings of the Survey in Germany have been published.

On 15 August 1945, President Truman requested that the Survey conduct a similar study of the effects of all types of air attack in the war against Japan, submitting reports in duplicate to the Secretary of War and to the Secretary of the Navy. The officers of the Survey during its Japanese phase were:

Franklin D'Olier, Chairman.
Paul H. Nitze, Henry C. Alexander, Vice Chairmen.
Walter Wilds, Secretary.
Harry L. Bowman.
J. K. Galbraith.
Rensis Likert.
Frank A. McNamee.
Fred Searls, Jr.
Monroe Spaght.
Dr. Louis R. Thompson.
Theodore P. Wright, Directors.

The Survey's complement provided for 300 civilians, 350 officers, and 500 enlisted men. The military segment of the organization was drawn from the Army to the extent of 60 percent, and from the Navy to the extent of 40 percent. Both the Army and Navy gave the Survey all possible assistance in furnishing men, supplies, transport, and information. The Survey operated from headquarters in Tokyo early in September 1945, with subheadquarters in Nagoya, Osaka, Hiroshima, and Nagasaki, and with mobile teams operating in other parts of Japan, the islands of the Pacific and the Asiatic mainland.

It was possible to reconstruct much of wartime Japanese military planning and execution, engagement by engagement and campaign by campaign, and to secure reasonably accurate statistics on Japan's economy and war production, plant by plant and industry by industry. In addition, studies were conducted on Japan's over-all strategic plans and the background of her entry into the war, the internal discussions and negotiations leading to her acceptance of unconditional surrender, the course of health and morale among the civilian population, the effectiveness of the Japanese civilian defense organization and the effects of the atomic bombs. Separate reports will be issued covering each phase of the study.

The Survey interrogated more than 700 Japanese military, government, and industrial officials. It also recovered and translated many documents which have not only been useful to the Survey, but will also furnish data valuable for other studies. Arrangements are being made to turn over the Survey's files to a permanent Government agency where they will be available for further examination and distribution.

I. INTRODUCTION

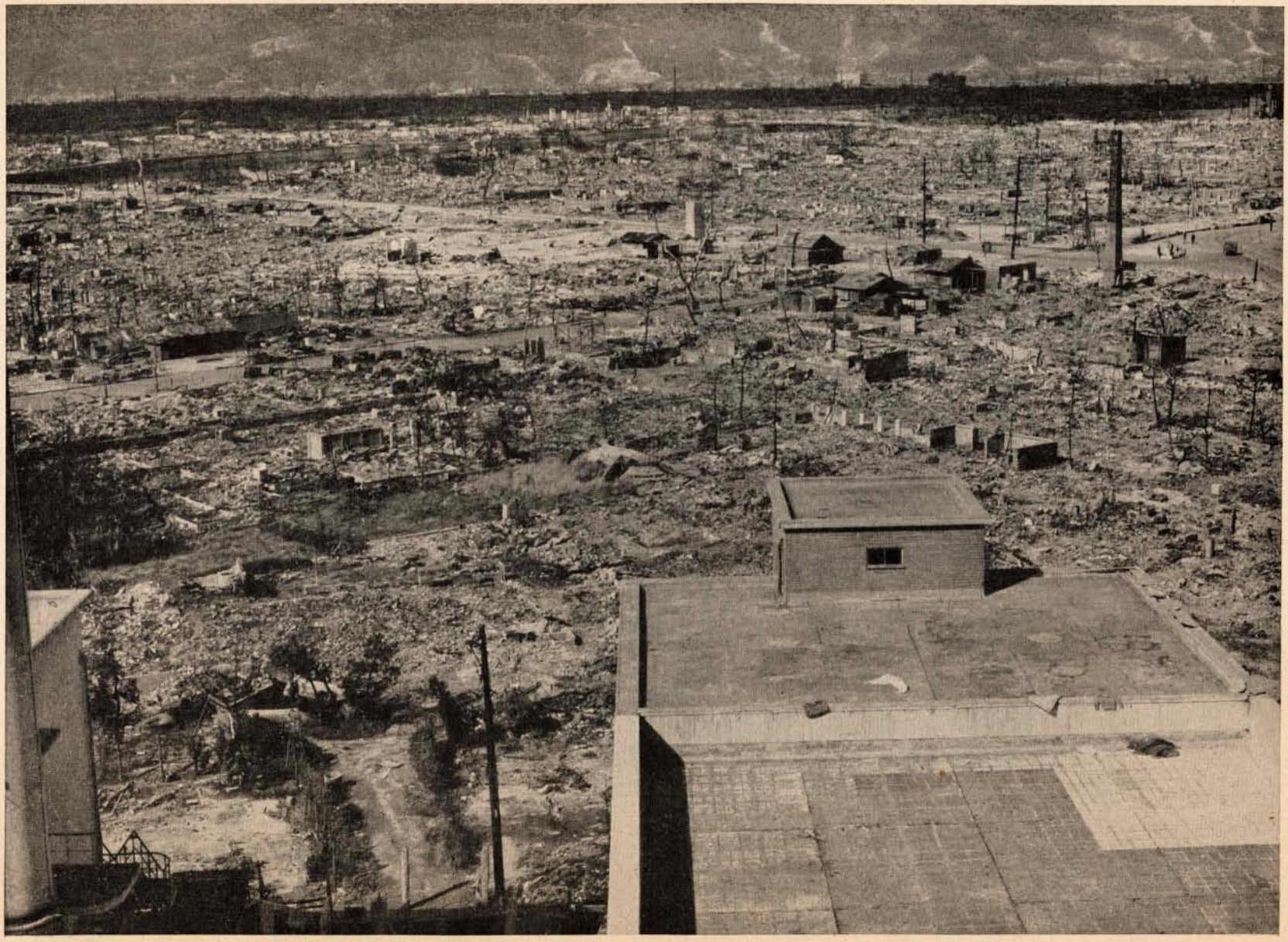
The available facts about the power of the atomic bomb as a military weapon lie in the story of what it did at Hiroshima and Nagasaki. Many of these facts have been published, in official and unofficial form, but mingled with distortions or errors. The United States Strategic Bombing Survey, therefore, in partial fulfillment of the mission for which it was established, has put together in these pages a fairly full account of just what the atomic bombs did at Hiroshima and Nagasaki. Together with an explanation of how the bomb achieved these effects, this report states the extent and nature of the damage, the casualties, and the political repercussions from the two attacks. The basis is the observation, measurement, and analysis of the Survey's investigators. The conjecture that is necessary for understanding of complex phenomena and for applying the findings to the problems of defense of the United States is clearly labelled.

When the atomic bombs fell, the United States Strategic Bombing Survey was completing a study of the effects of strategic bombing on Germany's ability and will to resist. A similar study of the effects of strategic bombing on Japan was being planned. The news of the dropping of the atomic bomb gave a new urgency to this project, for a study of the air war against Japan clearly involved new weapons and new possibilities of concentration of attack that might qualify or even change the conclusions and recommendations of the Survey as to the effectiveness of air power. The directors of the Survey, therefore, decided to examine exhaustively the effects of the atomic bombs, in order that the full impact on Japan and the implications of their results could be confidently analyzed. Teams of experts were selected to study the scenes of the bombings from the special points of emphasis of physical damage, civilian defense, morale, casualties, community life, utilities and transportation, various industries, and the general economic and political repercussions. In all, more than 110 men—engineers, architects, fire experts, economists, doctors, photographers, draftsmen—participated in the field study at each city, over a period of 10 weeks from October to December, 1945. Their detailed studies are now being published.

In addition, close liaison was maintained with other investigating units. Cooperation was received from, and extended to, the following groups:

The Joint Commission for the Investigation of the Atomic Bomb in Japan.
The British Mission to Japan.
The Naval Technical Mission to Japan.

Special acknowledgment is due to the medical groups of the Joint Commission, whose data and findings have been generously made available to the Survey. On medical aspects of the bombings, the Joint Commission was the chief fact-finding group; it will present its definitive report in the near future. In other fields, however—particularly the study of physical damage and the impact on community life—the Survey collected its own data and is the primary source.



HIROSHIMA—from the top of the Red Cross Hospital looking northwest. Frame buildings recently erected.

II. THE EFFECTS OF THE ATOMIC BOMBINGS

A. THE ATTACKS AND DAMAGE

1. *The attacks.*—A single atomic bomb, the first weapon of its type ever used against a target, exploded over the city of Hiroshima at 0815 on the morning of 6 August 1945. Most of the industrial workers had already reported to work, but many workers were enroute and nearly all the school children and some industrial employees were at work in the open on the program of building removal to provide firebreaks and disperse valuables to the country. The attack came 45 minutes after the "all clear" had been sounded from a previous alert. Because of the lack of warning and the populace's indifference to small groups of planes, the explosion came as an almost complete surprise, and the people had not taken shelter. Many were caught in the open, and most of the rest in flimsily constructed homes or commercial establishments.

The bomb exploded slightly northwest of the center of the city. Because of this accuracy and the flat terrain and circular shape of the city, Hiroshima was uniformly and extensively devastated. Practically the entire densely or moderately built-up portion of the city was leveled by blast and swept by fire. A "fire-storm," a phenomenon which has occurred infrequently in other conflagrations, developed in Hiroshima: fires springing up almost simultaneously over the wide flat area around the center of the city drew in air from all directions. The inrush of air easily overcame the natural ground wind, which had a velocity of only about 5 miles per hour. The "fire-wind" attained a maximum velocity of 30 to 40 miles per hour 2 to 3 hours after the explosion. The "fire-wind" and the symmetry of the built-up center of the city gave a roughly circular shape to the 4.4 square miles which were almost completely burned out.

The surprise, the collapse of many buildings, and the conflagration contributed to an unprecedented casualty rate. Seventy to eighty thousand people were killed, or missing and presumed dead, and an equal number were injured. The magnitude of casualties is set in relief by a comparison with the Tokyo fire raid of 9–10 March 1945, in which, though nearly 16 square miles were destroyed, the number killed was no larger, and fewer people were injured.

At Nagasaki, 3 days later, the city was scarcely more prepared, though vague references to the Hiroshima disaster had appeared in the newspaper of 8 August. From the Nagasaki Prefectural Report on the bombing, something of the shock of the explosion can be inferred:

> The day was clear with not very much wind—an ordinary midsummer's day. The strain of continuous air attack on the city's population and the severity of the summer had vitiated enthusiastic air raid precautions. Previously, a general alert had been sounded at 0748, with a raid alert at 0750; this was canceled at 0830, and the alertness of the people was dissipated by a great feeling of relief.

The city remained on the warning alert, but when two B–29's were again sighted coming in the raid signal was not given immediately; the bomb was dropped at 1102 and the raid signal was given a few minutes later, at 1109. Thus only about 400 people were in the city's tunnel shelters, which were adequate for about 30 percent of the population.

> When the atomic bomb exploded, an intense flash was observed first, as though a large amount of magnesium had been ignited, and the scene grew hazy with white smoke. At the same time at the center of the explosion, and a short while later in other areas, a tremendous roaring sound was heard and a crushing blast wave and intense heat were felt. The people of Nagasaki, even those who lived on the outer edge of the blast, all felt as though they had sustained a direct hit, and the whole city suffered damage such as would have resulted from direct hits everywhere by ordinary bombs.
>
> The zero area, where the damage was most severe, was almost completely wiped out and for a short while after the explosion no reports came out of that area. People who were in comparatively damaged areas reported their condition under the impression that they had received a direct hit. If such a great amount of damage could be wreaked by a near miss, then the power of the atomic bomb is unbelievably great.

710382°—46——2

NAGASAKI . . . "like a graveyard with not a tombstone standing . . ." Nagasaki Prefecture Report.

In Nagasaki, no fire storm arose, and the uneven terrain of the city confined the maximum intensity of damage to the valley over which the bomb exploded. The area of nearly complete devastation was thus much smaller; only about 1.8 square miles. Casualties were lower also; between 35,000 and 40,000 were killed, and about the same number injured. People in the tunnel shelters escaped injury, unless exposed in the entrance shaft.

The difference in the totals of destruction to lives and property at the two cities suggests the importance of the special circumstances of layout and construction of the cities, which affect the results of the bombings and must be considered in evaluating the effectiveness of the atomic bombs. An account of the nature and history of each city will give meaning to the details of the damage and disorganization at each.

2. *Hiroshima.*—The city of Hiroshima is located on the broad fan-shaped delta of the Ota River, whose 7 mouths divide the city into 6 islands which project fingerlike into Hiroshima Bay of the Inland Sea. These mouths of the river furnished excellent firebreaks in a city that is otherwise flat and only slightly above sea level. A highly developed bridge system, with 81 important bridges, joined the islands. A single kidney-shaped hill in the eastern part of the city, about one-half mile long and rising to an elevation of 221 feet, offered some blast protection to structures on the eastern side opposite the point of fall of the bomb. Otherwise, the city was uniformly exposed to the spreading energy from the bomb.

The city boundary extends to some low hills to the west and northeast and embraces 26.36 square miles, only 13 of which were built up. Seven square miles were densely or moderately built up, the remainder being occupied by sparsely built-up residential, storage, and transportation areas, vegetable farms, water courses, and wooded hilly sections. In the central area, no systematic separation of commercial, industrial, and residential zones existed, though there were rough functional sections. The main commercial district was located in the center of the city, and with the adjoining Chugoku Regional Army Headquarters occupied the greater portion of the central island. Residential areas and military barracks overlapped and surrounded this central area. The bulk of the industries was located on the perimeter of the city, either on the southern ends of the islands (where the Hiroshima airport was also situated) or to the east of the city. The 4 square miles of densely built-up area in the heart of the city—residential, commercial, and military—contained three-fifths of the total population. If there were, as seems probable, about 245,000 people in the city at the time of the attack, the density in the congested area must have been about 35,000 per square mile. Five completed evacuation programs and a sixth then in progress had reduced the population from its wartime peak of 380,000.

In Hiroshima (and in Nagasaki also) the dwellings were of wood construction; about one-half were one story and the remainder either one and one-half or two stories. The roof coverings were mostly hard-burnt black tile. There were no masonry division walls, and large groups of dwellings clustered together. The type of construction, coupled with antiquated fire-fighting equipment and inadequately trained personnel, afforded even in peacetime a high possibility of conflagration. Many wood-framed industrial buildings were of poor construction by American standards. The principal points of weakness were the extremely small tenons, the inadequate tension joints, and the inadequate or poorly designed lateral bracings. Reinforced concrete framed buildings showed a striking lack of uniformity in design and in quality of materials. Some of the construction details (reinforcing rod splices, for example) were often poor, and much of the concrete was definitely weak; thus some reinforced concrete buildings collapsed and suffered structural damage when within 2,000 feet of ground zero, and some internal wall paneling was demolished even up to 3,800 feet. (For convenience, the term "ground zero" will be used to designate the point on the ground directly beneath the point of detonation, or "air zero.") Other buildings, however, were constructed far more strongly than is required by normal building codes in America, to resist earthquakes. Furthermore, construction regulations in Japan have specified since the 1923 earthquake that the roof must safely carry a minimum load of 70 pounds per square foot whereas American requirements do not normally exceed 40 pounds per square foot for similar types. Though the regulation was not always followed, this extra strong construction was encountered in some of the buildings near ground zero at Hiroshima, and undoubtedly accounts for their ability to withstand atomic bomb

pressures without structural failures. Nearly 7 percent of the residential units had been torn down to make firebreaks.

Hiroshima before the war was the seventh largest city in Japan, with a population of over 340,000, and was the principal administrative and commercial center of the southwestern part of the country. As the headquarters of the Second Army and of the Chugoku Regional Army, it was one of the most important military command stations in Japan, the site of one of the largest military supply depots, and the foremost military shipping point for both troops and supplies. Its shipping activities had virtually ceased by the time of the attack, however, because of sinkings and the mining of the Inland Sea. It had been relatively unimportant industrially before the war, ranking only twelfth, but during the war new plants were built that increased its significance. These factories were not concentrated, but spread over the outskirts of the city; this location, we shall see, accounts for the slight industrial damage.

The impact of the atomic bomb shattered the normal fabric of community life and disrupted the organizations for handling the disaster. In the 30 percent of the population killed and the additional 30 percent seriously injured were included corresponding proportions of the civic authorities and rescue groups. A mass flight from the city took place, as persons sought safety from the conflagration and a place for shelter and food. Within 24 hours, however, people were streaming back by the thousands in search of relatives and friends and to determine the extent of their property loss. Road blocks had to be set up along all routes leading into the city, to keep curious and unauthorized people out. The bulk of the dehoused population found refuge in the surrounding contryside; within the city the food supply was short and shelter virtually nonexistent.

On 7 August, the commander of the Second Army assumed general command of the countermeasures, and all military units and facilities in the area were mobilized for relief purposes. Army buildings on the periphery of the city provided shelter and emergency hospital space, and dispersed Army supplies supplemented the slight amounts of food and clothing that had escaped destruction. The need far exceeded what could be made available. Surviving civilians assisted; although casualties in both groups had been heavy, 190 policemen and over 2,000 members of the Civilian Defense Corps reported for duty on 7 August.

The status of medical facilities and personnel dramatically illustrates the difficulties facing authorities. Of more than 200 doctors in Hiroshima before the attack, over 90 percent were casualties and only about 30 physicians were able to perform their normal duties a month after the raid. Out of 1,780 nurses, 1,654 were killed or injured. Though some stocks of supplies had been dispersed, many were destroyed. Only three out of 45 civilian hospitals could be used, and two large Army hospitals were rendered unusable. Those within 3,000 feet of ground zero were totally destroyed, and the mortality rate of the occupants was practically 100 percent. Two large hospitals of reinforced concrete construction were located 4,900 feet from ground zero. The basic structures remained erect but there was such severe interior damage that neither was able to resume operation as a hospital for some time and the casualty rate was approximately 90 percent, due primarily to falling plaster, flying glass, and fire. Hospitals and clinics beyond 7,000 feet, though often remaining standing, were badly damaged and contained many casualties from flying glass or other missiles.

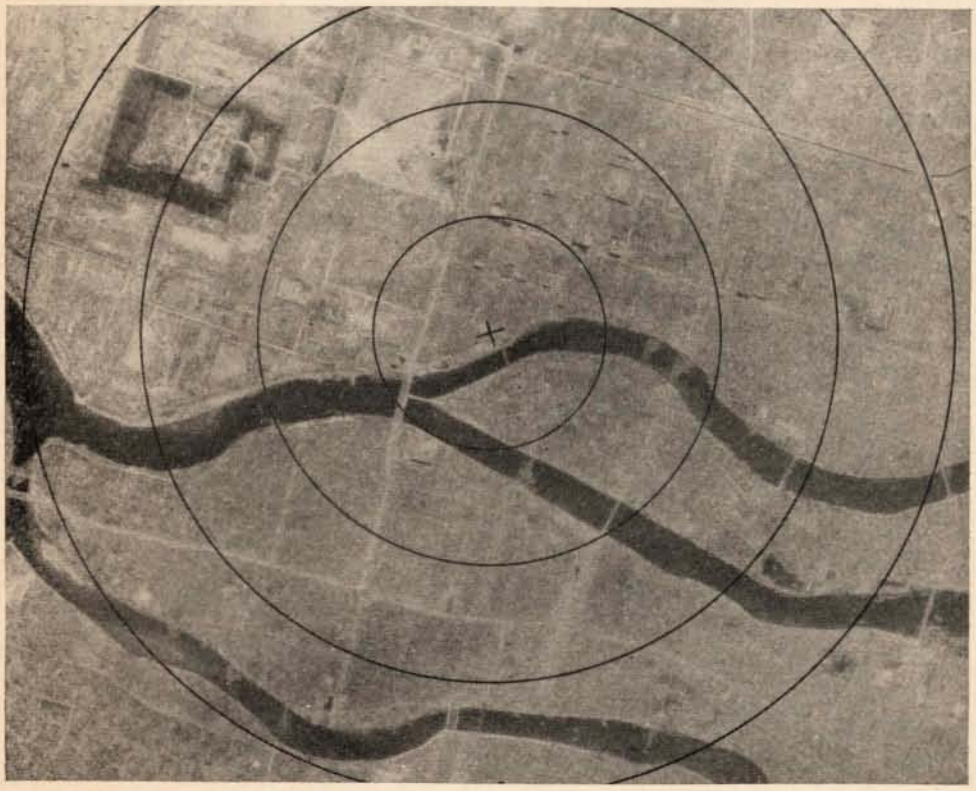
With such elimination of facilities and personnel, the lack of care and rescue activities at the time of the disaster is understandable; still, the eyewitness account of Father Siemes[1] shows how this lack of first-aid contributed to the seriousness of casualties. At the improvised first-aid stations, he reports:

> * * * Iodine is applied to the wounds but they are left uncleansed. Neither ointment nor other therapeutic agents are available. Those that have been brought in are laid on the floor and no one can give them any further care. What could one do when all means are lacking? Among the passersby, there are many who are uninjured. In a purposeless, insensate manner, distraught by the magnitude of the disaster, most of them rush by and none conceives the thought of organizing help on his own initiative. They are concerned only with the welfare of their own families—in the official aid stations and hospitals, a good third or half of those that had been brought in died. They lay about there almost without care, and a very high percentage succumbed. Everything was lacking, doctors, assistants, dressings, drugs, etc. * * *.

Effective medical help had to be sent in from the outside, and arrived only after a considerable delay.

Fire-fighting and rescue units were equally stripped of men and equipment. Father Siemes

[1] German-born Jesuit professor at Jochi University, Tokyo; in the Hiroshima area when the bomb fell.



HIROSHIMA before and after bombing. Area around ground zero. 1,000 foot circles.
A. A. F. Photos

reports that 30 hours elapsed before any organized rescue parties were observed. In Hiroshima, only 16 pieces of fire-fighting equipment were available for fighting the conflagration, three of them borrowed. However, it is unlikely that any public fire department in the world, even without damage to equipment or casualties to personnel, could have prevented development of a conflagration in Hiroshima, or combatted it with success at more than a few locations along its perimeter. The total fire damage would not have been much different.

All utilities and transportation services were disrupted over varying lengths of time. In most cases, however, the demand fell off even more precipitously than the available supply, and where the service was needed it could be restored at a minimal level. Thus, through railroad service was possible on 8 August, only 2 days after the attack, when fire trucks still had to be used to pump water into the locomotives because of insufficient water pressure. Electric power from the general network was available in most of the surviving parts of the city on 7 August, and only one plant, the Engineering Division of Mitsubishi Heavy Industries, was hampered in its recovery by the inability to obtain sufficient power for several weeks.

The water reservoir, which was of reinforced concrete and earth-covered, was undamaged; it was nearly 2 miles from the blast center. However, 70,000 breaks of pipe connections in buildings and dwellings were caused by blast and fire effects. No subsurface pipes were crushed and no leaks resulted from blast as a direct cause, though several leaks in underground mains resulted from falling debris. Pressure in the city center dropped to zero because of the connection breaks and the damage to a 16- and a 14-inch water main where they crossed damaged bridges. Six sewer pumping stations were rendered inoperable by fire and blast within a radius of 1 mile. The remaining eight stations were only slightly damaged, but no effort was made to repair or operate them. Water tables rose at flood periods and lands behind revetments were inundated.

Trolley cars, trucks, and railroad rolling stock suffered extensive damage. Transportation buildings (offices, stations, living quarters, and a few warehouses) were damaged by fire in the passenger station area, but damage was slight to the roundhouses, transit sheds, warehouses, and repair units in the classification and repair area. About 200 railroad employees were killed, but by 20 August, 14 days after the attack, 80 percent of the employees were at work.

The electric power transmission and distribution system was wrecked; only power equipment of rugged construction, such as transformers, resisted the blast and heat within the devastated areas. Instruments were damaged beyond repair, and switches, switchyard insulators, cables, and copper bus work were rendered unusable. The telephone system was approximately 80 percent damaged, and no service was restored until 15 August 1945.

Industry in the center of the city was effectively wiped out. Though small workshops numbered several thousand, they represented only one-fourth of the total industrial production of Hiroshima, since many of them had only one or two workers. The bulk of the city's output came from large plants located on the outskirts of the city; one-half of the industrial production came from only five firms. Of these larger companies, only one suffered more than superficial damage. Of their working force, 94 percent were uninjured. Since electric power was available, and materials and working force were not destroyed, plants ordinarily responsible for nearly three-fourths of Hiroshima's industrial production could have resumed normal operation within 30 days of the attack had the war continued.

Immediately after the attack, the presence of these nearly intact industries spurred countermeasures in an effort to retain for the nation's war effort the potential output of the city. The prefectural governor issued a proclamation on 7 August, calling for "a rehabilitation of the stricken city and an aroused fighting spirit to exterminate the devilish Americans." To prevent the spread of rumors and brace morale, 210,000 out-of-town newspapers were brought in daily to replace the destroyed local paper. With the surrender, however, reconstruction took on a slower tempo. On 16 August, regular rationing was resumed. Care of the injured and disposal of corpses remained urgent, but other steps were few.

By 1 November, the population of Hiroshima was back to 137,000. The city required complete rebuilding. The entire heart, the main administrative and commercial as well as residential section, was gone. In this area only about 50 buildings, all of reinforced concrete, remained standing. All of these suffered blast damage and all save about a dozen were almost completely gutted by fire; only 5 could be used without major re-

pairs. These burnt-out structural frames rose impressively from the ashes of the burned-over section where occasional piles of rubble or twisted steel skeletons marked the location of brick or steel frame structures. At greater distances light steel frame and brick structures remained undamaged. Blast damage to wood-frame buildings and to residences extended well beyond the burned-over area, gradually becoming more erratic and spotty as distances were reached where only the weakest buildings were damaged, until in the outer portions of the city only minor disturbances of the tile roofs or breakage of glass were visible. The official Japanese figures summed up the building destruction at 62,000 out of a total of 90,000 buildings in the urban area, or 69 percent. An additional 6,000 or 6.6 percent were severely damaged, and most of the others showed glass breakage or disturbance of roof tile. These figures show the magnitude of the problem facing the survivors.

Despite the absence of sanitation measures, no epidemics are reported to have broken out. In view of the lack of medical facilities, supplies, and personnel, and the disruption of the sanitary system, the escape from epidemics may seem surprising. The experience of other bombed cities in Germany and Japan shows that this is not an isolated case. A possible explanation may lie in the disinfecting action of the extensive fires. In later weeks, disease rates rose, but not sharply.

3. *Nagasaki.*—Nagasaki is located on the best natural harbor of western Kyushu, a spacious inlet in the mountainous coast. The city is a highly congested urban pattern extending for several miles along the narrow shores and up the valleys opening out from the harbor. Two rivers, divided by a mountain spur, form the two main valleys in whose basins the city lies: the Urakami River, in whose basin the atomic bomb fell, running into the harbor from a NNW direction, and the Nakashima River, running from the NE. This mountain spur and the irregular layout of the city effectively reduced the area of destruction.

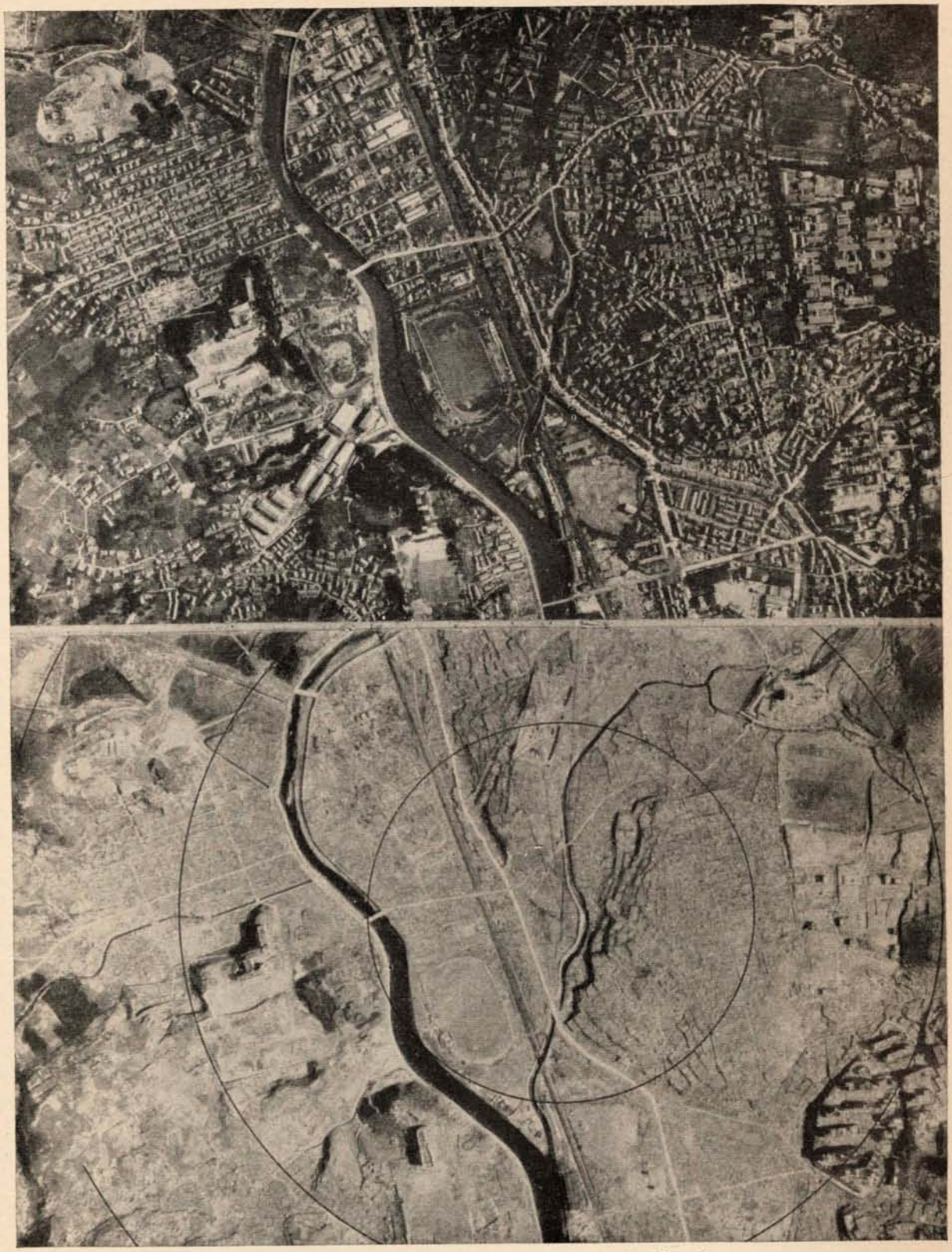
The main residential and commercial districts are intermingled in these two river basins. The large industrial plants stretch up the west shore of the bay and up the Urakami Valley. Though the metropolitan area of the city is officially about 35 square miles and stretches far into the countryside, the heavily built-up area is confined by the terrain to less than 4 square miles. The greatest population density thus approximated 65,000 per square mile even after the evacuations.

Despite its excellent harbor, Nagasaki's commercial importance, though great in previous centuries, had declined in recent years because of the city's isolated peninsular position and the difficulties of transportation through the mountains by inadequate roads and railroad facilities. As a naval base it had been supplanted by Sasebo. Industry gradually increased in importance, primarily under Mitsubishi influence. The four largest companies in the city were the Mitsubishi Shipyards, Electrical Equipment Works, Arms Plant, and Steel Works, employing nearly 90 percent of the city's labor force. Administratively, Nagasaki was by 1941 of merely local importance despite being the seat of the prefectural government.

Before the atomic bombing on 9 August, Nagasaki had experienced five small-scale air attacks in the previous 12 months, by an aggregate of 136 planes which dropped a total of 270 tons of high explosive, 53 tons of incendiary, and 20 tons of fragmentation bombs.

Of these, a raid of 1 August 1945 was most effective, with several bombs falling in the Mitsubishi Shipyards and Steel Works. The scale of effect can be roughly measured, however, by comparing the toll of building damage with that from the atomic bomb; in all these raids 276 residential buildings and 21 industrial buildings were destroyed or badly damaged. When the atomic bomb fell, Nagasaki was comparatively intact.

Because the most intense destruction was confined to the Urakami Valley, the impact of the bomb on the city as a whole was less shattering than at Hiroshima. In addition, no fire storm occurred; indeed, a shift in wind direction helped control the fires. Medical personnel and facilities were hard-hit, however. Over 80 percent of the city's hospital beds and the Medical College were located within 3,000 feet of the center of the explosion, and were completely destroyed. Reinforced concrete buildings within this range, though standing, were completely gutted by fire; buildings of wooden construction were destroyed by fire and blast. The mortality rate in this group of buildings was between 75 and 80 percent. Exact casualty figures for medical personnel are unknown, but the city seems to have fared better than Hiroshima: 120 doctors were at work on 1 November, about one-half of the preraid roster.



GROUND ZERO AT NAGASAKI—Before and after bombing.

A. A. F. Photos.

Casualties were undoubtedly high: 600 out of 850 medical students at the Nagasaki Medical College were killed and most of the others injured; and of the 20 faculty members, 12 were killed and 4 others injured.

Utilities and services were again disrupted. Both gas plants were destroyed, and the replacement time was estimated at several months. Though the basic water supply was not affected, thousands of residential feeder-line breaks were supplemented by eight breaks on a 14-inch main line and four breaks where another main line crossed a bridge. Electric power distribution and transmission systems were effectively destroyed in the area of heaviest destruction, but power could be supplied to the other parts of the city almost immediately.

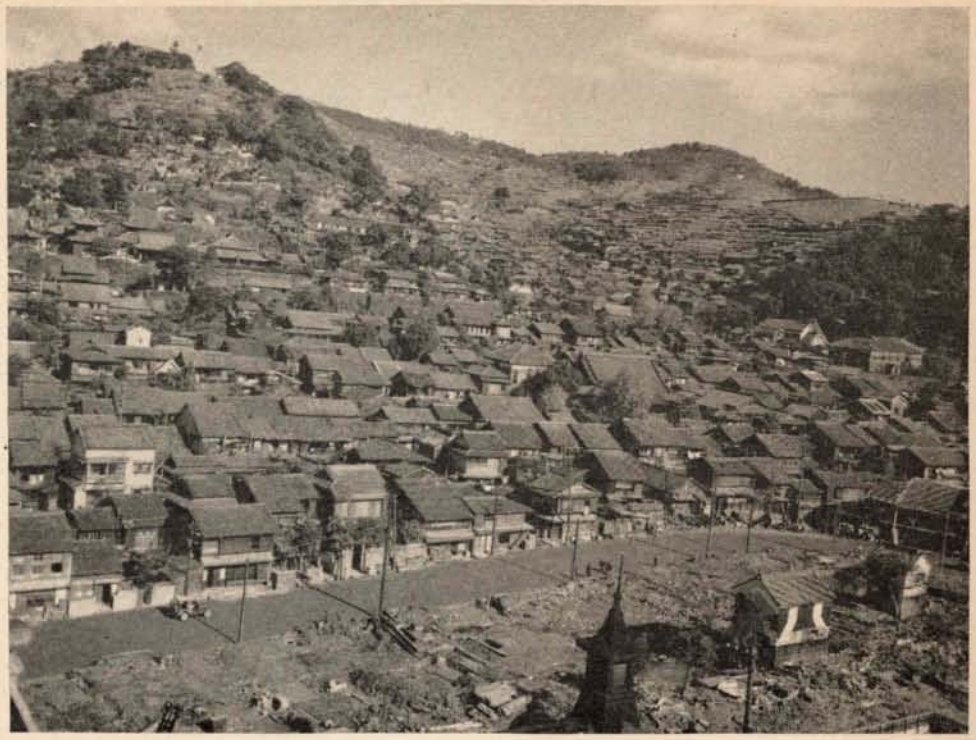
Shipping was virtually unaffected. Trolley service was halted both by the interruption in power supply and by damage to street cars. Nagasaki is at the end of a railroad spur line. The major damage was sustained by track and railroad bridges. The rails buckled intermittently for a distance of 5,000 to 7,500 feet from ground zero, at points where burning debris set fire to wooden cross ties. Three bridges were displaced; rails were distorted and the tracks had to be completely rebuilt. The railroad stations were completely destroyed by blast and fire and the electric signal system was severely damaged. Rolling stock was slightly damaged, primarily by fire. Although the damage to equipment was not extensive, it was severe enough to curtail traffic for 48 hours, during which time sufficient emergency repair work was performed to permit resumption of limited traffic.

Control of relief measures was in the hands of the prefecture. The sequence of clearance and repair activities illustrates the activities that were carried on.

The city's repair facilities were completely disorganized by the atomic bomb, so that with the single exception of shutting off water to the affected areas no repairs were made to roads, bridges, water mains, or transportation installations by city forces. The prefecture took full responsibility for such restoration as was accomplished, delegating to the scattered city help the task of assisting in relief of victims. There were only 3 survivors of 115 employees of the street car company, and late as the middle of November 1945 no cars were running. A week after the explosion, the water works officials made an effort to supply water to persons attempting to live in the bombed-out areas, but the leakage was so great that the effort was abandoned. It fell to the prefecture, therefore, to institute recovery measures even in those streets normally the responsibility of the city. Of the entire public works construction group covering the Nagasaki city area, only three members appeared for work and a week was required to locate and notify other survivors. On the morning of 10 August, police rescue units and workers from the Kawaminami shipbuilding works began the imperative task of clearing the Omura-Nagasaki pike, which was impassable for 8,000 feet. A path 6½ feet wide was cleared despite the intense heat from smouldering fires, and by 15 August had been widened to permit two-way traffic. No trucks, only rakes and shovels, were available for clearing the streets, which were filled with tile, bricks, stone, corrugated iron, machinery, plaster, and stucco. Street areas affected by blast and not by fire were littered with wood. Throughout the devastated area, all wounded had to be carried by stretcher, since no motor vehicles were able to proceed through the cluttered streets for several days. The plan for debris removal required clearance of a few streets leading to the main highway; but there were frequent delays caused by the heat of smouldering fires and by calls for relief work. The debris was simply raked and shoveled off the streets. By 20 August the job was considered complete. The streets were not materially damaged by the bomb nor were the surface or the abutments of the concrete bridges, but many of the wooden bridges were totally or partially destroyed by fire.

Under the circumstances—fire, flight of entire families, destruction of official records, mass cremation—identification of dead and the accurate count of casualties was impossible. As at Hiroshima, the season of the year made rapid disposal of bodies imperative, and mass cremation and mass burial were resorted to in the days immediately after the attack. Despite the absence of sanitary measures, no epidemics broke out here. The dysentery rate rose from 25 per 100,000 to 125 per 100,000. A census taken on 1 November 1945 found a population of 142,700 in the city.

At Nagasaki, the scale of destruction was greater than at Hiroshima, though the actual area destroyed was smaller because of the terrain and the point of fall of the bomb. The Nagasaki Prefectural Report describes vividly the impress of the bomb on the city and its inhabitants:



RESIDENTIAL AREAS, NAGASAKI. Shielded by hills, one congested area survived (note firebreak in the foreground).

Another, 1,000 feet northeast of ground zero was reduced to rubble.

Within a radius of 1 kilometer from ground zero, men and animals died almost instantaneously from the tremendous blast pressure and heat; houses and other structures were smashed, crushed and scattered; and fires broke out. The strong complex steel members of the structures of the Mitsubishi Steel Works were bent and twisted like jelly and the roofs of the reinforced concrete National Schools were crumpled and collapsed, indicating a force beyond imagination. Trees of all sizes lost their branches or were uprooted or broken off at the trunk.

Outside a radius of 1 kilometer and within a radius of 2 kilometers from ground zero, some men and animals died instantly from the great blast and heat, but the great majority were seriously or superficially injured. Houses and other structures were completely destroyed while fires broke out everywhere. Trees were uprooted and withered by the heat.

Outside a radius of 2 kilometers and within a radius of 4 kilometers from ground zero, men and animals suffered various degrees of injury from window glass and other fragments scattered about by the blast and many were burned by the intense heat. Dwelling and other structures were half damaged by blast.

Outside a radius of 4 kilometers and within a radius of 8 kilometers from the ground zero, living creatures were injured by materials blown about by the blast; the majority were only superficially wounded. Houses were half or only partially damaged.

While the conflagration with its uniformly burnt-out area caught the attention at Hiroshima, the blast effects, with their resemblance to the aftermath of a hurricane, were most striking at Nagasaki. Concrete buildings had their sides facing the blast stove in like boxes. Long lines of steel-framed factory sheds, over a mile from ground zero, leaned their skeletons away from the explosion. Blast resistant objects such as telephone poles leaned away from the center of the explosion; on the surrounding hills trees were blown down within considerable areas. Although there was no general conflagration, fires contributed to the total damage in nearly all concrete structures. Evidence of primary fire is more frequent than at Hiroshima.

Because parts of the city were protected by hills, more than one-half of the residential units escaped serious damage. Of the 52,000 residential units in the city on 1 August, 14,146 or 27.2 percent were completely destroyed (by Japanese count) (11,494 of these were burned); 5,441 or 10.5 percent were half-burned or destroyed; many of the remaining units suffered superficial or minor damage. In 558 nonresidential buildings in the built-up area of Nagasaki which the Survey studied, almost 60 percent of the usable floor area was destroyed or structurally damaged. Only 12 percent was undamaged, the rest suffering superficial or minor damage.

The survival of a higher percentage of the buildings, then, distinguishes Nagasaki from Hiroshima, so also, on the other hand, does the damage to factories. In Nagasaki, only the Mitsubishi Dockyards among the major industries was remote enough from the explosion to escape serious damage. The other three Mitsubishi firms, which were responsible together with the dockyards for over 90 percent of the industrial output of the city, were seriously damaged. The Arms Plant and the Steel Works were in the main area of damage. Plant officials estimated that 58 percent of the value of the former and 78 percent of the value of the latter were destroyed: Survey investigators considered the two plants to be 50 percent destroyed. The Mitsubishi Electric Works were on the edge of the main area of destruction, but suffered 10 percent structural damage.

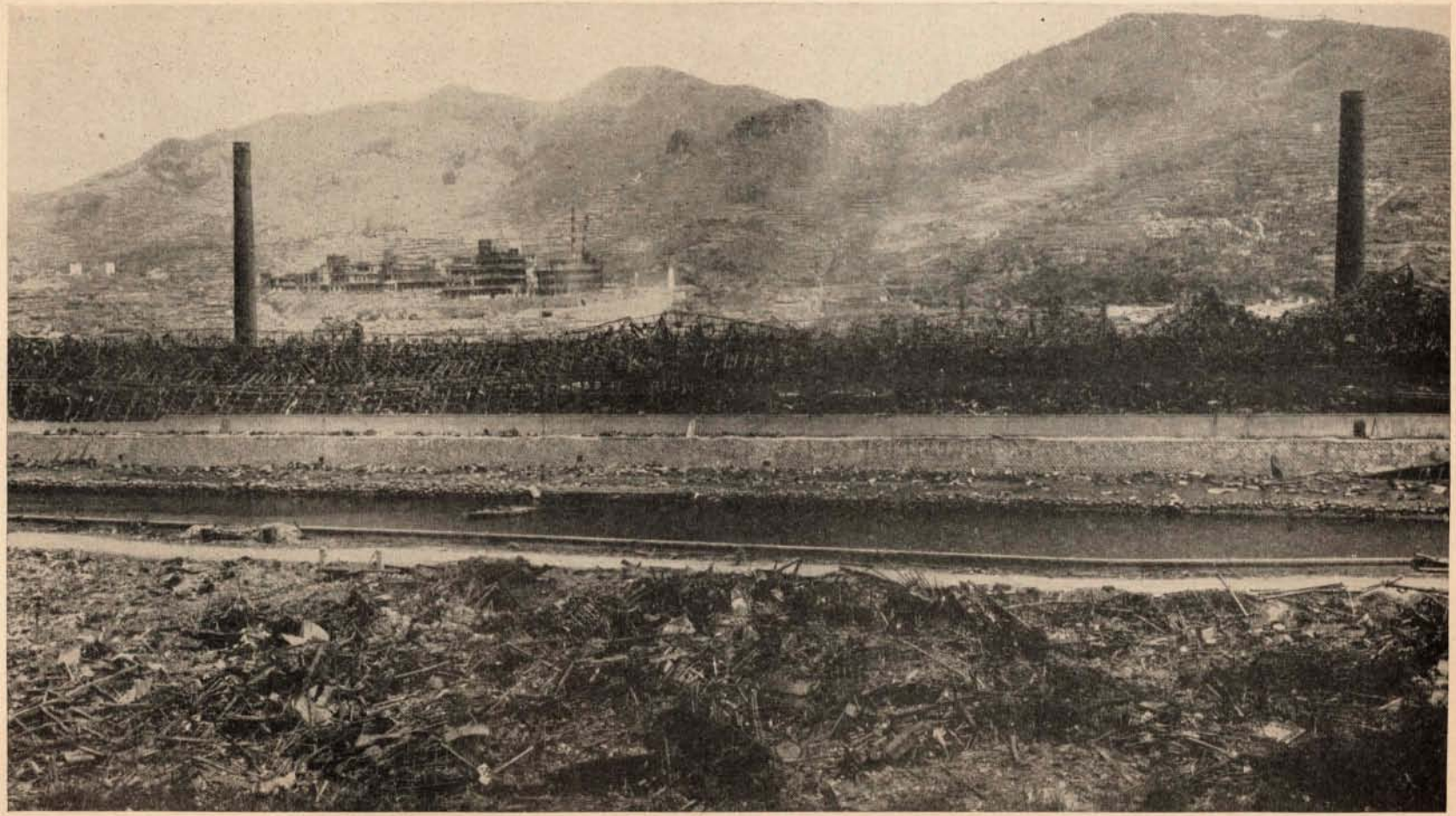
One or two paragraphs from the report of the commanding officer of Sasebo Naval District will illustrate the sort of damage done to industrial installations. Of two plants of the Mitsubishi Arms Works, he reports:

With the exception of the tunnel workshops and the half-underground workshops, the Ohashi and Mori Machi Plants were completely destroyed by collapse. Reinforced concrete structures in these plants were severely damaged internally—ceilings collapsed, fittings of all sorts were destroyed, and equipment was damaged. Casting and forging shops in the Ohashi Plant were destroyed by fire, which broke out in those structures. The Mori Machi Plant was nearly completely destroyed by fire. Taking both plants together, 60 percent of the machinery installations was damaged. In the Ohashi Plant, from 80 to 90 percent of the machinery can be used again; in the Mori Machi Plant only 40 to 50 percent of the machinery can be used in the future.

Or of the Mitsubishi Steel Works:

Plant structures here (some north-light steel framed structures) suffered extensive damage to roofs and walls as steel plates were blown off. The frames themselves were bent, twisted, or toppled over, and several buildings caught fire. Hardly any of the machinery in the plant can be used again in its present condition. However, nearly 70 percent of the machinery can be repaired.

In general, (as has proved true with high explosive or incendiary bombs also) the damage to machinery and other contents of a factory was less than damage to the buildings. In addition, the air burst of the atomic bomb meant that it acted indirectly on machine tools and other building



THE TREMENDOUS PRESSURE OF THE BLAST bent the steel frame of the Mitsubishi Steel Works (about 2,400 feet south of ground zero at Nagasaki) away from the explosion. Nagasaki Medical University Hospital in background. (Photo taken 26 August 1945 by Japanese.)

contents. Though a few tools were blown over by blast, almost all the serious damage was caused by debris from damaged buildings, overturning through mass movement of buildings, or burning of buildings.

Thus the extent and sort of damage to machinery depended on the construction of the buildings housing them. In wood-frame buildings, 95 percent of the machines were seriously damaged, but in reinforced concrete or steel framed buildings only one-third or one-fourth of the machines were affected seriously. As would be expected, fire caused much damage to machines in timber framed shops (practically all of which were destroyed up to 7,000 feet from ground zero) and some damage in other types of structure. Debris was a major cause of damage only in certain reinforced concrete buildings, where walls and roofs collapsed.

Shortage of raw materials had reduced operations at these four Mitsubishi plants to a fraction of their capacity. Had the raw material situation been normal and had the war continued, it is estimated that restoration of production would have been possible though slow. The dockyard, which was affected mainly by the 1 August attack rather than by the atomic bomb, would have been able to produce at 80 percent of full capacity within 3 or 4 months. The steel works would have required a year to get into substantial production, the electric works could have resumed production at a reduced rate within 2 months and been back at capacity within 6 months, and the arms plants would have required 15 months to reach two-thirds of their former capacity.

B. GENERAL EFFECTS

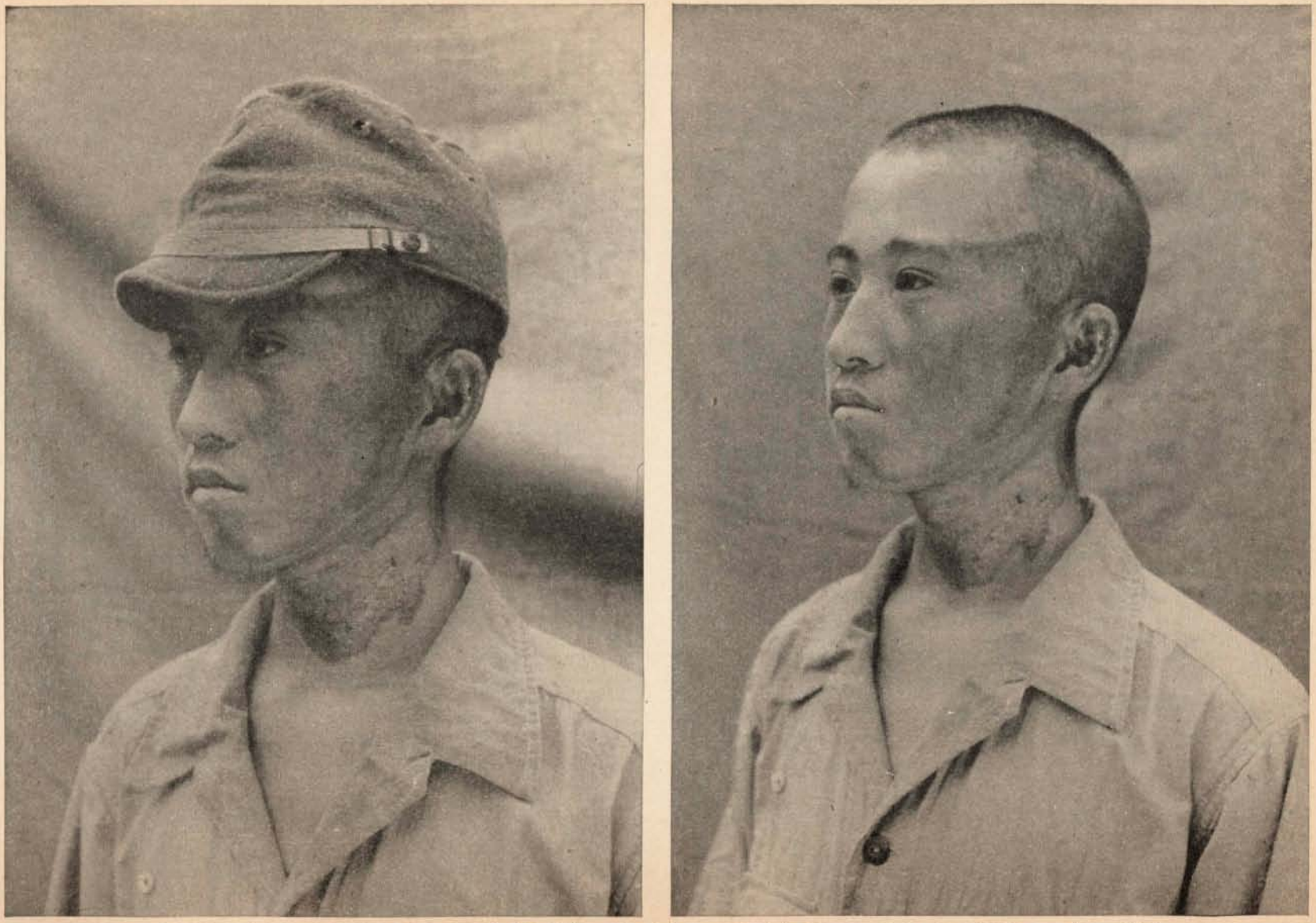
1. *Casualties.*—The most striking result of the atomic bombs was the great number of casualties. The exact number of dead and injured will never be known because of the confusion after the explosions. Persons unaccounted for might have been burned beyond recognition in the falling buildings, disposed of in one of the mass cremations of the first week of recovery, or driven out of the city to die or recover without any record remaining. No sure count of even the preraid populations existed. Because of the decline in activity in the two port cities, the constant threat of incendiary raids, and the formal evacuation programs of the Government, an unknown number of the inhabitants had either drifted away from the cities or been removed according to plan. In this uncertain situation, estimates of casualties have generally ranged between 100,000 and 180,000 for Hiroshima, and between 50,000 and 100,000 for Nagasaki. The Survey believes the dead at Hiroshima to have been between 70,000 and 80,000, with an equal number injured; at Nagasaki over 35,000 dead and somewhat more than that injured seems the most plausible estimate.

Most of the immediate casualties did not differ from those caused by incendiary or high-explosive raids. The outstanding difference was the presence of radiation effects, which became unmistakable about a week after the bombing. At the time of impact, however, the causes of death and injury were flash burns, secondary effects of blast and falling debris, and burns from blazing buildings. No records are available that give the relative importance of the various types of injury, especially for those who died immediately after the explosion. Indeed, many of these people undoubtedly died several times over, theoretically, since each was subjected to several injuries, any one of which would have been fatal. The Hiroshima prefectural health department placed the proportion of deaths from burns (flash or flame) at 60 percent, from falling debris at 30 percent, and from other injuries at 10 percent; it is generally agreed that burns caused at least 50 percent of the initial casualties. Of those who died later, an increasing proportion succumbed to radiation effects.

The seriousness of these radiation effects may be measured by the fact that 95 percent of the traced survivors of the immediate explosion who were within 3,000 feet suffered from radiation disease. Colonel Stafford Warren, in his testimony before the Senate Committee on Atomic Energy, estimated that radiation was responsible for 7 to 8 percent of the total deaths in the two cities. Most medical investigators who spent some time in the areas feel that this estimate is far too low; it is generally felt that no less than 15 to 20 percent of the deaths were from radiation. In addition, there were an equal number who were casualties but survived, as well as uncounted thousands who probably were affected by the gamma rays but not enough to produce definite illness.

A plausible estimate of the importance of the various causes of death would range as follows:

Flash burns, 20 to 30 percent.
Other injuries, 50 to 60 percent.
Radiation sickness, 15 to 20 percent.



PROTECTION AGAINST RADIANT HEAT. This patient (photographed by Japanese 2 October 1945) was about 6,500 feet from ground zero when the rays struck him from the left. His cap was sufficient to protect the top of his head against flash burns.

If we examine the nature of the casualties under each group of causes we find familiar and unfamiliar effects.

Flash burns.—The flash of the explosion, which was extremely brief, emitted radiant heat travelling at the speed of light. Flash burns thus followed the explosion instantaneously. The fact that relatively few victims suffered burns of the eyeballs should not be interpreted as an indication that the radiant heat followed the flash, or that time was required to build up to maximum heat intensity. The explanation is simply that the structure of the eye is more resistant to heat than is average human skin, and near ground zero the recessed position of the eyeball offered protection from the overhead explosion. Peak temperatures lasted only momentarily.

Survivors in the two cities stated that people who were in the open directly under the explosion of the bomb were so severely burned that the skin was charred dark brown or black and that they died within a few minutes or hours.

Among the survivors, the burned areas of the skin showed evidence of burns almost immediately after the explosion. At first there was marked redness, and other evidence of thermal burns appeared within the next few minutes or hours, depending on the degree of the burn. Uninfected burns healed promptly without any unusual clinical features, according to the Japanese physicians who attended the cases. American medical observers noted only a tendency to formation of excess scar tissue, which could be satisfactorily explained as the result of malnutrition and the large degree of secondary infection that complicated healing of the burns. There were also a few instances of burns healing with contractures and limitation of the mobility of certain joints, such as the elbows or knees. In many instances, these primary burns of minor nature were completely healed before patients developed evidence of radiation effects.

Because of the brief duration of the flash wave and the shielding effects of almost any objects—leaves and clothing as well as buildings—there were many interesting cases of protection. The radiant heat came in a direct line like light, so that the area burned corresponded to this directed exposure. Persons whose sides were toward the explosion often showed definite burns of both sides of the back while the hollow of the back escaped. People in buildings or houses were apparently burned only if directly exposed through the windows. The most striking instance was that of a man writing before a window. His hands were seriously burned but his exposed face and neck suffered only slight burns due to the angle of entry of the radiant heat through the window.

Flash burns were largely confined to exposed areas of the body, but on occasion would occur through varying thicknesses of clothing. Generally speaking, the thicker the clothing the more likely it was to give complete protection against flash burns. One woman was burned over the shoulder except for a T-shaped area about one-fourth inch in breadth; the T-shaped area corresponded to an increased thickness of the clothing from the seam of the garment. Other people were burned through a single thickness of kimono but were unscathed or only slightly affected underneath the lapel. In other instances, skin was burned beneath tightly fitting clothing but was unburned beneath loosely fitting portions. Finally, white or light colors reflected heat and afforded some protection; people wearing black or dark-colored clothing were more likely to be burned.

Other injuries.—Because of the combination of factors at the area near the center of the explosion, the casualty effects of blast are hard to single out. If it is remembered that even directly under the explosion, people were several hundred feet away from the air-burst, it will be easier to understand why true blast effects were relatively rare. Only toward the periphery of the affected zone was the blast effect lateral and likely to throw people violently against buildings, and at the periphery the intensity of the blast had fallen off sharply. Comparatively few instances were reported of arms or legs being torn from the body by flying debris. Another indication of the rarity of over-pressure is the scarcity of ruptured eardrums. Among 106 victims examined by the Japanese in Hiroshima on 11 and 12 August, only three showed ruptured eardrums; a study done in October at the Omura hospital near Nagasaki revealed that only two of 92 cases had ruptured eardrums. Only at Nagasaki were there reports of over-pressure in the shock wave. Some of the dead were said by survivors to have had their abdomens ruptured and intestines protruding; others were reported to have protruding eyes and tongues, and to have looked as if they had drowned. Thorough check by Allied investigators discredited these stories as evidence of di-

rect blast effects; the normal effects of blast are internal hemorrhage and crushing. These external signs point to injuries from debris rather than blast.

Injuries produced by falling and flying debris were much more numerous, and naturally increased in number and seriousness nearer the center of the affected area. The collapse of the buildings was sudden, so that thousands of people were pinned beneath the debris. Many were able to extricate themselves or received aid in escaping, but large numbers succumbed either to their injuries or to fire before they could be extricated. The flimsiness of Japanese residental construction should not be allowed to obscure the dangers of collapse; though the walls and partitions were light, the houses had heavy roof timbers and heavy roof tiles. Flying glass from panels also caused a large number of casualties, even up to 15,000 feet from ground zero.

The number of burns from secondary fires was slight among survivors, but it was probable that a large number of the deaths in both cities came from the burning of people caught in buildings. Eyewitness accounts agree that many fatalities occurred in this way, either immediately or as a result of the lack of care for those who did extricate themselves with serious burns. There are no references, however, to people in the streets succumbing either to heat or to carbon monoxide as they did in Tokyo or in Hamburg, Germany. A few burns resulted from clothing set afire by the flash wave, but in most cases people were able to beat out such fires without serious injury to the skin.

Radiation disease.—The radiation effects upon survivors resulted from the gamma rays liberated by the fission process rather than from induced radio-activity or the lingering radio-activity of deposits of primary fission products. Both at Nagasaki and at Hiroshima, pockets of radio-activity have been detected where fission products were directly deposited, but the degree of activity in these areas was insufficient to produce casualties. Similarly, induced radio-activity from the interaction of neutrons with matter caused no authenticated fatalities. But the effects of gamma rays—here used in a general sense to include all penetrating high-frequency radiations and neutrons that caused injury—are well established, even though the Allies had no observers in the affected areas for several weeks after the explosions.

Our understanding of radiation casualties is not complete. In part the deficiency is in our basic knowledge of how radiation affects animal tissue. In the words of Dr. Robert Stone of the Manhattan Project, "The fundamental mechanism of the action of radiation on living tissues has not been understood. All methods of treatment have therefore been symptomatic rather than specific. For this reason, studies into the fundamental nature of the action of radiation have been carried on to some extent, the limitation being that it was unlikely that significant results could be obtained during the period of war."

According to the Japanese, those individuals very near the center of the explosion but not affected by flash burns or secondary injuries became ill within 2 or 3 days. Bloody diarrhea followed, and the victims expired, some within 2 to 3 days after the onset and the majority within a week. Autopsies showed remarkable changes in the blood picture—almost complete absence of white blood cells, and deterioration of bone marrow. Mucous membranes of the throat, lungs, stomach, and the intestines showed acute inflammation.

The majority of the radiation cases, who were at greater distances, did not show severe symptoms until 1 to 4 weeks after the explosion, though many felt weak and listless on the following day. After a day or two of mild nausea and vomiting, the appetite improved and the person felt quite well until symptoms reappeared at a later date. In the opinion of some Japanese physicians, those who rested or subjected themselves to less physical exertion showed a longer delay before the onset of subsequent symptoms. The first signs of recurrence were loss of appetite, lassitude, and general discomfort. Inflammation of the gums, mouth, and pharynx appeared next. Within 12 to 48 hours, fever became evident. In many instances it reached only 100° Fahrenheit and remained for only a few days. In other cases, the temperature went as high as 104° or 106° Fahrenheit. The degree of fever apparently had a direct relation to the degree of exposure to radiation. Once developed, the fever was usually well sustained, and in those cases terminating fatally it continued high until the end. If the fever subsided, the patient usually showed a rapid disappearance of other symptoms and soon regained his feeling of good health. The other symptoms commonly seen were shortage of white corpuscles, loss of hair, inflammation and gangrene of the gums, inflammation of the mouth and pharynx, ulcera-

tion of the lower gastro-intestinal tract, small livid spots (petechiae) resulting from escape of blood into the tissues of the skin or mucous membrane, and larger hemorrhages of gums, nose and skin.

Loss of hair usually began about 2 weeks after the bomb explosion, though in a few instances it is reported to have begun as early as 4 to 5 days afterward. The areas were involved in the following order of frequency with variations depending on the degree of exposure: scalp, armpits, beard, pubic region, and eyebrows. Complete baldness was rare. Microscopic study of the body areas involved has shown atrophy of the hair follicles. In those patients who survived after 2 months, however, the hair has commenced to regrow. An interesting but unconfirmed report has it that loss of the hair was less marked in persons with grey hair than in those with dark hair.

A decrease in the number of white blood corpuscles in the circulating blood appears to have been a constant accompaniment of radiation disease, even existing in some milder cases without other radiation effects. The degree of leukopenia was probably the most accurate index of the amount of radiation a person received. The normal white blood count averages 5,000 to 7,000: leukopenia is indicated by a count of 4,000 or less. The white blood count in the more severe cases ranged from 1,500 to 0, with almost entire disappearance of the bone marrow. The moderately severe cases showed evidence of degeneration of bone marrow and total white blood counts of 1,500 to 3,000. The milder cases showed white blood counts of 3,000 to 4,000 with more minor degeneration changes in the bone marrow. The changes in the system for forming red blood corpuscles developed later, but were equally severe.

Radiation clearly affected reproduction, though the extent has not been determined. Sterility has been a common finding throughout Japan, especially under the conditions of the last 2 years, but there are signs of an increase in the Hiroshima and Nagasaki areas to be attributed to the radiation. Sperm counts done in Hiroshima under American supervision revealed low sperm counts or complete aspermia for as long as 3 months afterward in males who were within 5,000 feet of the center of the explosion. Cases dying of radiation disease showed clear effects on spermatogenesis. Study of sections of ovaries from autopsied radiation victims has not yet been completeted. The effects of the bomb on pregnant women are marked, however. Of women in various stages of pregnancy who were within 3,000 feet of ground zero, all known cases have had miscarriages. Even up to 6,500 feet they have had miscarriages or premature infants who died shortly after birth. In the group between 6,500 and 10,000 feet, about one-third have given birth to apparently normal children. Two months after the explosion, the city's total incidence of miscarriages, abortions, and premature births was 27 percent as compared with a normal rate of 6 percent. Since other factors than radiation contributed to this increased rate, a period of years will be required to learn the ultimate effects of mass radiation upon reproduction.

Treatment of victims by the Japanese was limited by the lack of medical supplies and facilities. Their therapy consisted of small amounts of vitamins, liver extract, and an occasional blood transfusion. Allied doctors used penicillin and plasma with beneficial effects. Liver extract seemed to benefit the few patients on whom it was used: It was given in small frequent doses when available. A large percentage of the cases died of secondary disease, such as septic bronchopneumonia or tuberculosis, as a result of lowered resistance. Deaths from radiation began about a week after exposure and reached a peak in 3 to 4 weeks. They had practically ceased to occur after 7 to 8 weeks.

Unfortunately, no exact definition of the killing power of radiation can yet be given, nor a satisfactory account of the sort and thickness of concrete or earth that will shield people. From the definitive report of the Joint Commission will come more nearly accurate statements on these matters. In the meanwhile the awesome lethal effects of the atomic bomb and the insidious additional peril of the gamma rays speak for themselves.

There is reason to believe that if the effects of blast and fire had been entirely absent from the bombing, the number of deaths among people within a radius of one-half mile from ground zero would have been almost as great as the actual figures and the deaths among those within 1 mile would have been only slightly less. The principal difference would have been in the time of the deaths. Instead of being killed outright as were most of these victims, they would have survived for a few days or even 3 or 4 weeks, only to die eventually of radiation disease.

These suppositions have vital importance, for

actually in Nagasaki and Hiroshima many people who were protected by structures against blast and fire were not protected against the effect of gamma rays. The complexity of the problem of shelter protection has been increased by this necessity of shielding against radiant heat and gamma rays. Fortunately, earth and concrete will shield against gamma rays, the required thickness varying with the intensity of the rays.

The slow and inadequate treatment of victims by the Japanese probably contributed to the high casualty rates. Many persons could undoubtedly have been saved had facilities, supplies, and personnel been available immediately after the bombings. Probably the number of deaths from the true blast effects, flame burns, or serious injuries from collapsing structures would not have been altered appreciably; generally speaking, these cases either were killed outright or else survived. Many of the flash burn cases could have been saved with tremendous quantities of plasma and parenteral fluids if treatment could have begun within a few hours after the bombing. Probably the most significant results could have been achieved with the radiation cases. With large quantities of whole blood and adequate supportive treatment, possibly 10 to 20 percent of those dying of radiation might have survived. However, it is doubtful that 10 percent of all the deaths resulting from the atomic bombs could have been avoided with the best medical care. A more likely figure is 5 to 8 percent.

2. *Morale.*[2]—As might be expected, the primary reaction to the bomb was fear—uncontrolled terror, strengthened by the sheer horror of the destruction and suffering witnessed and experienced by the survivors. Between one-half and two-thirds of those interviewed in the Hiroshima and Nagasaki areas confessed having such reactions, not just for the moment but for some time. As two survivors put it:

> Whenever a plane was seen after that, people would rush into their shelters: They went in and out so much that they did not have time to eat. They were so nervous they could not work.
>
> After the atomic bomb fell, I just couldn't stay home. I would cook, but while cooking I would always be watching out and worrying whether an atomic bomb would fall near me.

The behavior of the living immediately after the bombings, as described earlier, clearly shows the state of shock that hindered rescue efforts. A Nagasaki survivor illustrates succinctly the mood of survivors:

> All I saw was a flash and I felt my body get warm and then I saw everything flying around. My grandmother was hit on the head by a flying piece of roof and she was bleeding * * * I became hysterical seeing my grandmother bleeding and we just ran around without knowing what to do.
>
> I was working at the office. I was talking to a friend at the window. I saw the whole city in a red flame, then I ducked. The pieces of the glass hit my back and face. My dress was torn off by the glass. Then I got up and ran to the mountain where the good shelter was.

The two typical impulses were those: Aimless, even hysterical activity or flight from the city to shelter and food.

The accentuated effect of these bombs came not only from the surprise and their crushing power, but also from the feeling of security among the inhabitants of the two cities before the attacks. Though Nagasaki had undergone five raids in the previous year, they had not been heavy, and Hiroshima had gone almost untouched until the morning of 6 August 1945. In both cities many people felt that they would be spared, and the various rumors in circulation supporting such feeling covered a wide range of wishful thoughts. There were so many Christians there, many Japanese-Americans came from Hiroshima, the city was a famous beauty spot—these and other even more fantastic reasons encouraged hopes. Other people felt vaguely that their city was being saved for "something big," however.

Such a shattering event could not fail to have its impact on people's ways of thinking. Study of the patterns of belief about the war, before and after the bombing, show this change clearly. Prior to the dropping of the atomic bombs, the people of the two target cities appear to have had fewer misgivings about the war than people in other cities. Response to set questions indicate that among Japanese civilians prior to 1 July 1945:

59 percent in the Hiroshima-Nagasaki areas but
74 percent in the other urban areas entertained doubts about a Japanese Victory;
31 percent in Hiroshima-Nagasaki but
47 percent in other urban areas felt certain that victory for Japan was impossible;
12 percent in Hiroshima-Nagasaki but

[2] An U. S. S. B. S. Morale division team interviewed a scientifically selected sample of almost 250 persons: 128 from Hiroshima and Nagasaki cities, and 120 from the immediately surrounding areas. The same standard questions were put to these people and similar groups in representative Japanese cities.

34 percent in other urban areas had reached a point where they felt unable to continue the war.

Further,

28 percent of the people of Japan as a whole said they had never reached a point where they felt they could not go on with the war, whereas

39 percent of the people in the Hiroshima-Nagasaki areas said they had never reached such a point.

These figures clearly suggest that the will to resist had indeed been higher in the "atomic bomb cities" than in Japan as a whole.

There is no doubt that the bomb was the most important influence among the people of these areas in making them think that defeat was inevitable. An additional 28 percent stated that after the atomic bomb was dropped they became convinced that victory for Japan was impossible. Almost one-fourth admitted that because of the bombing they felt personally unable to carry on. Forty percent testified to various degrees of defeatism induced by the atomic bomb. Significantly, certainty of defeat was much more prevalent at Hiroshima, where the area of devastation and the casualties were greater, than at Nagasaki.

Typical comments of survivors were:

If the enemy has this type of bomb, everyone is going to die, and we wish the war would hurry and finish.

I did not expect that it was that powerful. I thought we have no defense against such a bomb.

One of my children was killed by it, and I didn't care what happened after that.

Other reactions were found. In view of their experiences, it is not remarkable that some of the survivors (nearly one-fifth) hated the Americans for using the bomb or expressed their anger in such terms as "cruel," "inhuman," and "barbarous."

* * * they really despise the Americans for it, the people all say that if there are such things as ghosts, why don't they haunt the Americans?

When I saw the injured and killed, I felt bitter against the emeny.

After the atomic bomb exploded, I felt that now I must go to work in a munitions plant * * *. My sons told me that they wouldn't forget the atomic bomb even when they grow up.

The reaction of hate and anger is not surprising, and it is likely that in fact it was a more extensive sentiment than the figures indicate, since unquestionably many respondents, out of fear or politeness, did not reveal their sentiments with complete candor. Despite this factor, the frequency of hostile sentiments seems low. Two percent of the respondents even volunteered the observation that they did not blame the United States for using the bomb. There is evidence that some hostility was turned against their own Government, either before or after the surrender, although only a few said they wondered why their nation could not have made the bomb. In many instances the reaction was simply one of resignation. A common comment was, "Since it was war, it was just shikata-ga-nai (Too bad)."

Admiration for the bomb was more frequently expressed than anger. Over one-fourth of the people in the target cities and surrounding area said they were impressed by its power and by the scientific skill which underlay its discovery and production.

Of greater significance are the reactions of the Japanese people as a whole. The two raids were all-Japan events and were intended so: The Allied Powers were trying to break the fighting spirit of the Japanese people and their leaders, not just of the residents of Hiroshima and Nagasaki. Virtually all the Japanese people had a chance to react to the bomb though the news had not reached to full spread at the time of the surrender. By the time the interviewing was done, only about 2 percent of the population in rural areas and 1 percent in the cities had not heard of the bomb.

The reactions found in the bombed cities appeared in the country as a whole—fear and terror, anger and hatred against the users, admiration for the scientific achievement—though in each case with less intensity. The effect of the bomb on attitudes toward the war in Japan as a whole was, however, much less marked than in the target cities. While 40 percent of the latter respondents reported defeatist feelings induced by the bomb, 28 percent of those in the islands as a whole attributed such reactions to the news of the bomb. There are at least three possible explanations of this difference. First, the level of confidence was quite low in Japan well before the time of the atomic bombing. Prior to 1 July 1945 doubts about a Japanese victory were felt by 74 percent of the population. By the same data 47 percent had become certain that a Japanese victory was impossible, and 34 percent felt that they could not go on with the war. Under these circumstances, the announcement of a new and devastating

weapon was merely an addition to the already eloquent evidence of national weakness. Second, the reaction of those at some distance from the target cities seems to have been blunted by their direct experience with other sorts of misfortunes and hardships, the common phenomenon of psychological distance increasing with geographical distance. In Japan as a whole, for example, military losses and failures, such as those at Saipan, the Philippines, and Okinawa, were twice as important as this atomic bomb in inducing certainty of defeat. Other raids over Japan as a whole were more than three times as important in this respect. Consumer deprivations, such as food shortages and the attendant malnutrition, were also more important in bringing people to the point where they felt they could not go on with the war.

Third, the lack of understanding of the meaning of the new weapon in areas away from the target undoubtedly limited its demoralizing effect. As distance from the target cities increased, the effectiveness of the bombs in causing certainty of defeat declined progressively:

Group of cities:	*Percent of population certain of defeat because of atomic bomb*
Hiroshima - Nagasaki	25
Cities nearest to target cities	23
Cities near to target cities	15
Cities far from target cities	8
Cities farthest from target cities	6

Only in the nearest group of cities, within 40 miles of Hiroshima or Nagasaki, was there a substantial effect on morale. Were the channels of mass communication as readily available to all the population as they are in the United States and had the use of the bomb received anything like the intensive coverage it had here, the effect on continued support of the war would probably have been greater. Something approaching such knowledge, of course, probably would have spread rather widely had the war continued many more weeks, whether sanctioned by the censors or spread by the ever-active rumor channels so common in the country.

It is apparent that the effect of the atomic bombings on the confidence of the Japanese civilian population was remarkably localized. Outside of the target cities, it was subordinate to other demoralizing experiences. The effect which it did have was probably due largely to the number of casualties and the nature of the injuries received. These consequences were in part the result of surprise and the vulnerability of the raid defense system. Properly enforced warnings, precautions and an emergency care organization of the scale of the bomb's effects might have reduced casualties and, therefore, the effects on morale.

Even in the target cities, it must be emphasized, the atomic bombs did not uniformly destroy the Japanese fighting spirit. Hiroshima and Nagasaki, when compared with other Japanese cities, were not more defeatist than the average. The bombs were tremendous personal catastrophes to the survivors, but neither time nor understanding of the revolutionary threat of the atomic bomb permitted them to see in these personal catastrophes a final blow to Japan's prospects for victory or negotiated peace.

3. *The Japanese decision to surrender.*—The further question of the effects of the bombs on the morale of the Japanese leaders and their decision to abandon the war is tied up with other factors. The atomic bomb had more effect on the thinking of Government leaders than on the morale of the rank and file of civilians outside of the target areas. It cannot be said, however, that the atomic bomb convinced the leaders who effected the peace of the necessity of surrender. The decision to seek ways and means to terminate the war, influenced in part by knowledge of the low state of popular morale, had been taken in May 1945 by the Supreme War Guidance Council.

As early as the spring of 1944, a group of former prime ministers and others close to the Emperor had been making efforts toward bringing the war to an end. This group, including such men as Admiral Okada, Admiral Yonai, Prince Konoye, and Marquis Kido, had been influential in effecting Tojo's resignation and in making Admiral Suzuki Prime Minister after Koiso's fall. Even in the Suzuki cabinet, however, agreement was far from unanimous. The Navy Minister, Admiral Yonai, was sympathetic, but the War Minister, General Anami, usually represented the fight-to-the-end policy of the Army. In the Supreme War Guidance Council, a sort of inner cabinet, his adherence to that line was further assured by the participation of the Army and Navy chiefs of staff, so that on the peace issue this organization was evenly divided, with these three opposing the Prime Minister, Foreign Minister, and Navy Minister. At any time military (especially Army) dissatisfaction with the Cabinet might have eventuated at least in its fall and possibly in the "liquidation" of the antiwar members.

Thus the problem facing the peace leaders in the Government was to bring about a surrender despite the hesitation of the War Minister and the opposition of the Army and Navy chiefs of staff. This had to be done, moreover, without precipitating counter measures by the Army which would eliminate the entire peace group. This was done ultimately by bringing the Emperor actively into the decision to accept the Potsdam terms. So long as the Emperor openly supported such a policy and could be presented to the country as doing so, the military, which had fostered and lived on the idea of complete obedience to the Emperor, could not effectively rebel.

A preliminary step in this direction had been taken at the Imperial Conference on 26 June. At this meeting, the Emperor, taking an active part despite his custom to the contrary, stated that he desired the development of a plan to end the war as well as one to defend the home islands. This was followed by a renewal of earlier efforts to get the Soviet Union to intercede with the United States, which were effectively answered by the Potsdam Declaration on 26 July and the Russian declaration of war on 9 August.

The atomic bombings considerably speeded up these political maneuverings within the government. This in itself was partly a morale effect, since there is ample evidence that members of the Cabinet were worried by the prospect of further atomic bombings, especially on the remains of Tokyo. The bombs did not convince the military that defense of the home islands was impossible, if their behavior in Government councils is adequate testimony. It did permit the Government to say, however, that no army without the weapon could possibly resist an enemy who had it, thus saving "face" for the Army leaders and not reflecting on the competence of Japanese industrialists or the valor of the Japanese soldier. In the Supreme War Guidance Council voting remained divided, with the war minister and the two chiefs of staff unwilling to accept unconditional surrender. There seems little doubt, however, that the bombing of Hiroshima and Nagasaki weakened their inclination to oppose the peace group.

The peace effort culminated in an Imperial conference held on the night of 9 August and continued into the early hours of 10 August, for which the stage was set by the atomic bomb and the Russian war declaration. At this meeting the Emperor, again breaking his customary silence, stated specifically that he wanted acceptance of the Potsdam terms.

A quip was current in high Government circles at this time that the atomic bomb was the real Kamikaze, since it saved Japan from further useless slaughter and destruction. It is apparent that in the atomic bomb the Japanese found the opportunity which they had been seeking, to break the existing deadlock within the Government over acceptance of the Potsdam terms.

III. HOW THE ATOMIC BOMB WORKS

Out of the stories of Hiroshima and Nagasaki can be built up, detail by detail, the picture of how the atomic bomb works—the different forms of energy given off, the velocity and intensity of each, the sort of effects each has on animate and inanimate objects. In these factors is the real story of what happened at Hiroshima and Nagasaki, for in them chance circumstances are ruled out.

Spectators' accounts, whether of the New Mexico, the Hiroshima, or the Nagasaki explosion, describe similar pictures. At Nagasaki, for example, the bomb exploded at 1102 with a tremendous flash of blue-white light, like a giant magnesium flare. The flash was accompanied by a rush of heat and was followed by a huge pressure wave and the rumbling sound of the explosion. Curiously enough, this sound was not distinctly noted by those who survived near the center of the explosion, although it was heard as far as 15 miles away. People on the hillsides in the country at a considerable distance from Nagasaki told of seeing the blue-white and then multicolored flash over the city, followed some seconds later by a tremendous clap, like thunder very close overhead. A huge snow-white cloud shot rapidly into the sky and the scene on the ground was obscured first by a bluish haze and then by a purple-brown cloud of dust and smoke.

The survivors were not aware at the time that a radically new bomb had been used. They were conscious of an explosion of tremendous power, but even the Government had no conception, until President Truman's announcement was broadcast, of the new principle of operation. If we strip our minds of any lingering prejudice that the atomic bomb is supernatural or incomprehensible in its operation, we shall see why its uniqueness was not at first recognized.

A. THE NATURE OF THE EXPLOSION

The atomic bomb works by explosion. An explosion is, in the words of the Smyth report, simply a "sudden and violent release of a large amount of energy in a small region." As do ordinary high explosives, atomic bombs release energy, though on an unprecedented scale. The energy takes three forms (one of which is new), and all the effects of the bomb can be referred directly to these three kinds of energy. They are:

(1) Heat (which is present in other explosions, as the familiar injuries known as "flash burns" on warships illustrate, but ordinarily not at high enough diffused temperatures to burn a man or set fire to combustible objects at any considerable distance from the explosion).

(2) Radiation (similar to X-rays or to that from radium).

(3) Blast or pressure (as from a demolition bomb).

The whole discussion of the effects of the atomic bomb will be phrased in terms of these three kinds of energy. No other more mysterious or immeasurable forces acted; these were all.

These were enough. The energy released in atomic explosion is of such magnitude and from so concentrated a source that it sets entirely new problems in its use or in protection against it. Ordinary burning or explosion is a chemical reaction in which energy is released during the rearrangement of the atoms of the explosive material. In an atomic reaction, however, the identity of the atoms, not simply their arrangement, is changed. The change is more fundamental: in it, matter is transformed into energy. The energy released when a pound of nitroglycerine explodes would, when converted into heat, raise the temperature of 150 pounds of water by 18° F. The explosion of a pound of uranium would produce an equal temperature rise in 2 billion pounds of water! Clearly, only a small part of the mass in the bomb's active core need be transformed to give an explosion of tremendous power.

At the time of the explosion, then, energy was given off in the forms of light, heat, gamma radiation, and pressure. The whole range of radiations, indeed, seems to have been present. There were heat radiations in the low frequency band

below infrared, visible waves of all colors (as the eyewitness accounts show), and penetrating radiations of very high frequency generally grouped as "gamma rays." Light and radiant heat ("flash heat") sped out in all directions at a rate of 186,000 miles per second, and the gamma rays at the same rate (though their effect was not immediately obvious). The shock waves travelled much more slowly. It may be inferred from tests with high explosives that the rate at a relative short distance from the point of explosion was about 2 miles per second, and dropped rapidly to the speed of sound, or about one-fifth of a mile per second. Thus the light, heat, and gamma radiation reached the target first, followed by shock and sound and the high winds of the blast.

B. HEAT

The center of the explosions—several hundred feet above ground—was a ball of fire. Because the radiant heat given off at the explosion easily charred combustible objects while ceasing so quickly that surfaces not in the direct line of radiation were unaffected, there are clearly marked "shadows" visible where objects were shielded against the heat. By projecting back the sharply defined outlines of these shadows, Japanese and Allied scientists have determined the height and diameter of the fireball. The two fireballs were apparently several hundred feet in diameter. The temperature at their core was virtually inconceivable—millions of degrees centigrade. Even at its edge, the temperature was several thousand degrees; reasoning from the heat effects observed on human beings, bubbled roof tile, and combustible materials, Japanese and Allied scientists have placed the figure variously between 3,000° and 9,000° C. Energy given off in heat alone was estimated by Japanese physicists at the astronomical figure of 10^{13} calories.

The flash heat was intense enough to cause fires, despite the distance of the fireball from the ground. Clothing ignited, though it could be quickly beaten out, telephone poles charred, thatched roofs of houses caught fire. In Hiroshima, the explosion started hundreds of fires almost simultaneously, the most distant of which was found 13,700 feet from ground zero; this, however, probably started when a building with a thatched roof collapsed onto a hot charcoal fire. Fires were started directly by flash heat in such easily ignitible substances as dark cloth, paper, or dry-rotted wood, within about 3,500 feet of ground zero; white-painted, concrete-faced or cement-stuccoed structures reflected the heat and did not ignite. A cedar bark roof and the top of a dry-rotted wooden platform 5,200 feet west of ground zero, were reported to have been ignited by the bomb flash. The majority of initial fires in buildings, however, were started by secondary sources (kitchen charcoal fires, electric short-circuits, industrial process fires, etc.). In Nagasaki, both Japanese and American fire experts agreed that more fires were caused directly than indirectly, in a ratio of 60 to 40. The range of primary fire there is reported to have exceeded 10,000 feet.

Charred telephone poles were discernible for 10,000 feet south and 13,000 feet north of ground zero at Hiroshima, and for 13,000 feet or more at Nagasaki. Bubbling of roof tile occurred at Hiroshima from ground zero out to 4,000 feet, though with only scattered frequency after 2,000 feet. The same phenomenon was reported at Nagasaki, accompanied again by scarring and peeling of granitic rocks, almost a mile from ground zero. A similar bubbled surface was obtained at the National Bureau of Standards by heating a sample of the tile to 1,800° C. for a period of 4 seconds. The effect so produced extended deeper into the tile than did the bubbling caused by the atomic bomb, which indicates that the explosion of the bomb subjected the tile to a temperature of more than 1,800° for less than 4 seconds.

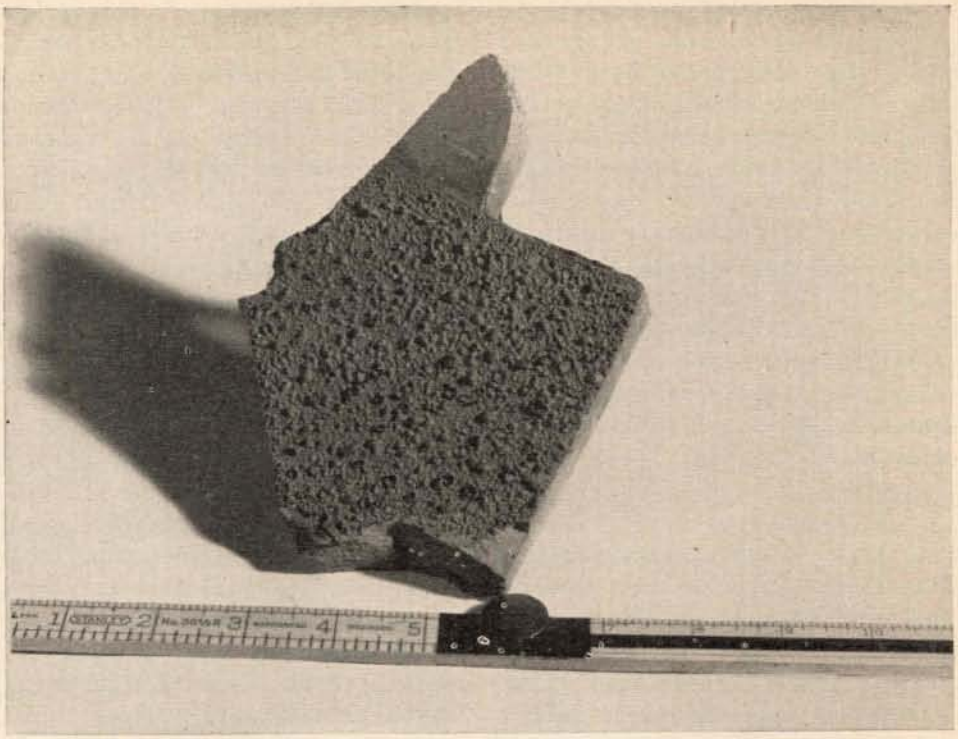
Persons reported feeling heat on their skin as far away as 24,000 feet. Burns of unprotected skin certainly occurred up to 12,000 to 13,000 feet, and reportedly up to 15,000 feet—nearly 3 miles. Serious or third-degree burns were suffered by those directly exposed within 4,500 feet, and occasionally as remote as 7,200 feet. In the immediate area of ground zero, the heat charred corpses beyond recognition.

Clothing as well as buildings afforded considerable protection against the flash. Even a clump of grass or tree leaf was, on occasion, adequate.

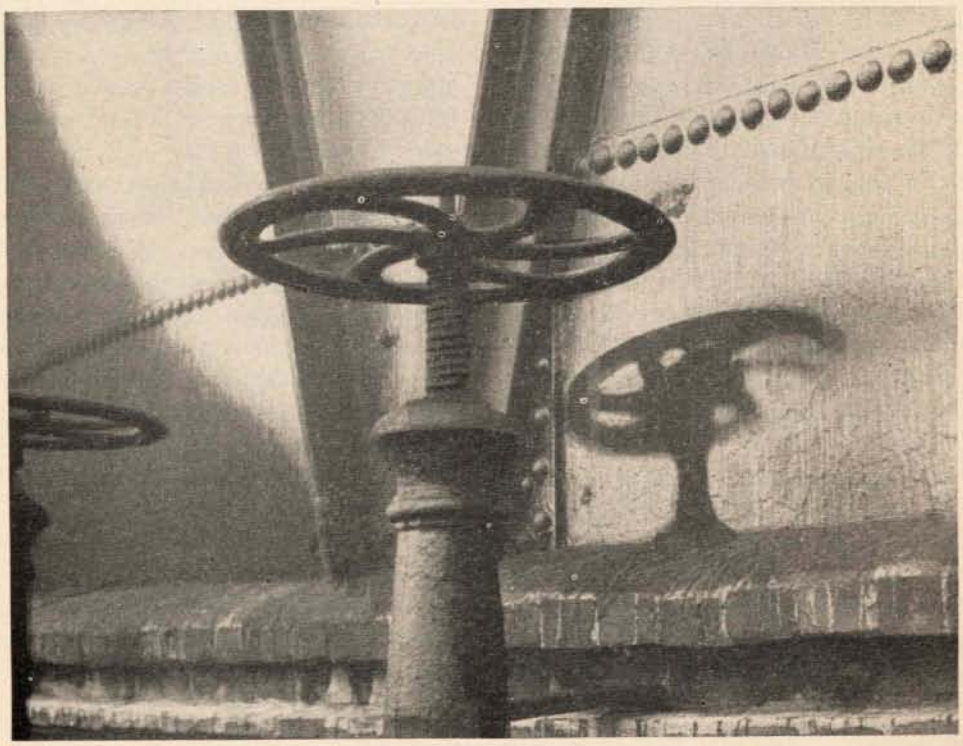
The implication clearly is that the duration of the flash was less than the time required for the grass or leaf to shrivel. While an accurate estimate is not possible, the duration could hardly have exceeded a fraction of a second.

C. RADIATION

From the chain reaction which produced the mass release of energy in the explosion, a wide



NAGASAKI—Blistered tile found at ground zero.



"Shadow" of hand valve wheel on paint of a gas holder at Hiroshima. Radiant heat instantly burned paint where the heat rays were not obstructed. 6,300 feet from ground zero (Japanese photo).

NEW SHOOTS are appearing on this limb of a chestnut tree, about 2,100 feet south of ground zero at Nagasaki, 2 months after the attack, even though the leaves were burned and withered at the time of the explosion (Japanese photo).

TREES SPLINTERED BY BLAST on a Nagasaki hillside, 2,700 feet southwest of ground zero (Japanese photo).

range of radiations were released. The light and heat are familiar elements of explosions, but the free neutrons and high-frequency radiations such as gamma rays are a new phenomenon. These radiations are highly penetrating and lethal.

The damaging penetration of radiation would be possible from three sources:

(*a*) From the high-frequency radiations, whether neutrons, gamma rays, or other unspecified rays, released in the chain reaction of the bomb.

(*b*) From lingering radioactivity from deposits of primary fission products scattered in the explosion.

(*c*) From induced radioactivity in the bombed area, caused by interaction of neutrons with matter penetrated.

Only the first cause seems to have had important effects, though there are detectable pockets of radioactivity in both cities. At Takasu, 10,000 feet from ground zero at Hiroshima, and at Nishiyama, 6,500 feet from ground zero in Nagasaki, scientific measurements weeks after the explosion showed radioactivity. Presumably this was from deposits of primary fission products rather than induced radioactivity. In tests of the ground and bones of victims of radiation disease, certain substances—phosphorus, barium, strontium, rare earths—have shown radioactivity. Though evidence of lingering radioactivity is slight, it is strong enough to leave open the ominous possibility of a different situation had the bomb exploded at ground level.

The radiation apparently had no lasting effects on the soil or vegetation: Seeds later planted within a few hundred feet of ground zero grew normally. Examination of subsurface soil in the immediate area showed presence of earthworms and other life only a few inches below the surface. The effect on human procreation is as yet undetermined, but pregnant women within a mile of ground zero showed an increased number of miscarriages, and there was in most cases a low sperm count among men in the same area. Stories of harmful effects on people who came into the area after the explosion have been disproved by investigation.

The rays proved lethal for an average radius of 3,000 feet from ground zero. They caused loss of hair up to 7,500 feet and occasionally beyond, and other mild effects up to almost 2 miles.

D. BLAST

The pressure or shock wave travelled out in all directions from the explosion. The blast effects produced were uniform, and essentially those of conventional large high-explosive weapons though on a much larger scale. Thus, instead of localized effects such as the collapse of a roof truss or wall panel, entire buildings were crushed or distorted as units.

The blast pressure, as with high explosives, rose almost instantaneously to a peak, declined more slowly, and then fell below atmospheric pressure for a period about three times the period during which it was above atmospheric pressure. The positive period—that during which the pressure was greater than atmospheric—was of much greater peak pressure than the succeeding, or negative phase. Short though the positive phase was—probably only slightly longer than a second—it lasted longer than the positive phase of ordinary bombs. Thus the effect of the atomic bomb on buildings was usually that of a powerful push which shoved buildings over or left them leaning, whereas high explosive bombs strike sharply and much more briefly and tend to punch holes in walls. The duration was also long enough so that almost all building failures came during the positive phase. Comparatively few evidences were found of failures of members during the longer but less intense negative phase; window shutters blown outwards toward the explosion were very rare.

Experiments with high explosives have shown that the face-on peak pressures are approximately two to five times as intense as side-on peak pressures; thus greater damage was inflicted on walls or roofs facing the blast than on similar surfaces parallel to the blast. Near ground zero, the blast struck almost vertically downward. Buildings were crushed if weak, or the roofs were crushed in with little or no damage to the walls. Trunks of trees remained standing, but stripped of their branches; telephone poles, pushed farther out, also remained erect near the center. Many small buildings were virtually engulfed in the pressure wave and simultaneously crushed from different directions. At somewhat greater distances, both horizontal and vertical components of the blast were appreciable, and buildings suffered damage both to roofs and to walls facing the explosion. At considerable distances, where the blast was travelling

BLAST STRUCK DOWNWARD against the roof of the Chinzei School, 1,500 feet from ground zero at Nagasaki, which had been taken over in part for munitions work. The fourth story collapsed completely, but the heavy earthquake-resistant structure protected some machine tools on the first floor from serious damage. Electric transformers and a switchboard did not escape; a combination of blast, fire, and debris destroyed them.

in an almost horizontal direction, damage was predominantly inflicted on walls during the blast. In such cases, the buildings were often completely racked by the inability of roof truss members to transmit the pressure to the far walls.

Shielding was more important at Nagasaki than at Hiroshima, because of the hills that divided the city. Building restrictions in Japan after the 1923 earthquake limited building heights to 100 feet; thus there was little shielding by buildings from these airburst bombs.

Reflection and diffraction effects were observed. Had the blast travelled in completely straight lines, more buildings would have survived in Nagasaki than actually did. Reflection effects were most clearly observed in the destruction of parapet walls of roofs on the side away from the bomb, where reflection of the blast wave from the roof reinforced the blast impinging on the wall directly. They were also visible in the displacing and cracking of concrete decks of bridges within 1,000 feet of ground zero, where reflection of the blast wave from the water struck the bridges where their resistance was least.

The resistance of buildings depended very largely on their construction, as two examples show.

(*a*) In the area betwen 2,000 and 3,000 feet from ground zero at Nagasaki, only 9.5 percent of the floor area of reinforced concrete buildings was destroyed or structurally damaged. Yet in the ring between 4,000 and 5,000 feet from ground zero, 56 percent of such buildings was destroyed or structurally damaged. Careful examination showed that the difference lay solely in design, construction detail, and materials: The bomb detonated over a section containing the most carefully and strongly built buildings in the city, the majority multistory earthquake resistant structures. This strength more than compensated for the greater intensity of blast. A rapidly diminishing blast was capable of serious damage to weaker buildings further away, mostly high, single-story industrial buildings, with thin, shell-type, arch roofs.

(*b*) At both cities, steel-framed buildings with corrugated asbestos walls and roofs suffered less structural damage than those with corrugated iron or sheet-metal walls and roofs. The corrugated asbestos crumbled easily, permitting the blast pressure to equalize itself rapidly around the main framing members, but the steel siding transferred the pressure to the structural members, causing distortion or general collapse.

The limits of blast effects extended 8 miles out, where some glass reportedly shattered in Hiroshima; at the same city, some roof stripping and disturbance of tiles was inflicted at the Japan Steel Co., 4.1 miles from ground zero.

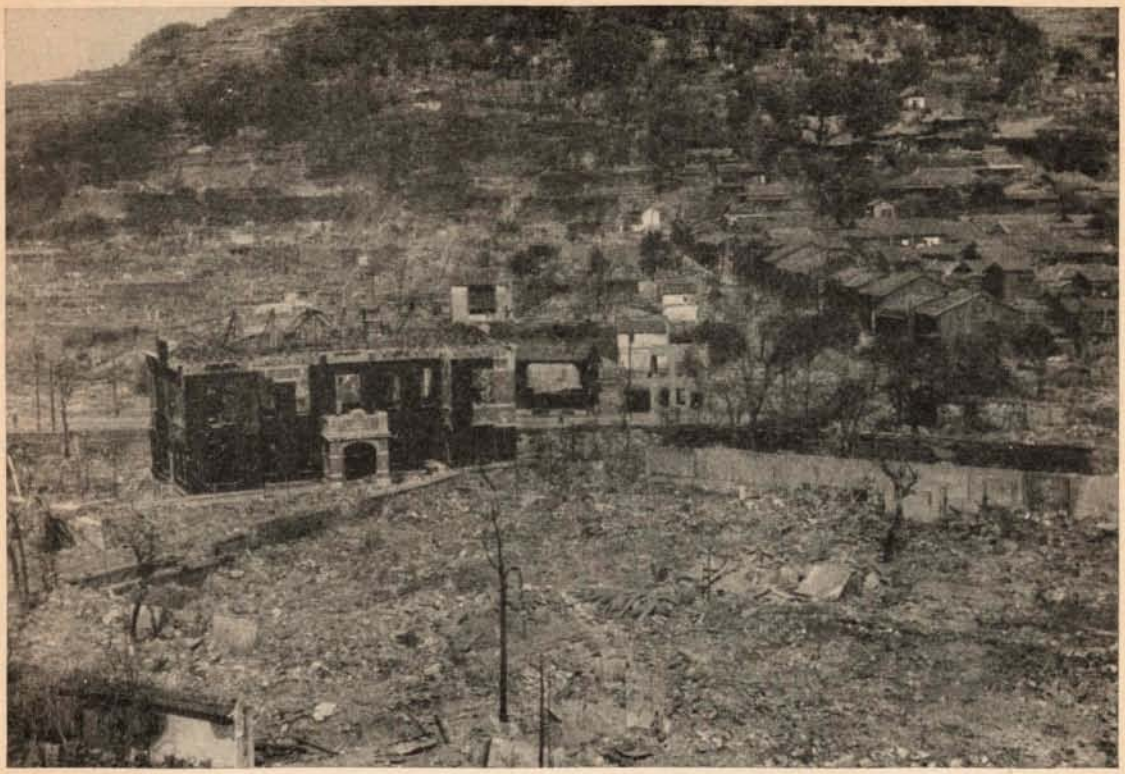
In analyzing the extent of the destruction wrought by the bombs, it is necessary to discriminate between the two cities and between different types of buildings. Equivalent effects are found at Nagasaki over greater areas. Structural damage to reinforced concrete buildings, both earthquake resistant and nonearthquake resistant, occurred within an area of 0.05 square mile at Hiroshima, but at Nagasaki similar severe damage was inflicted in an area of 0.43 square mile.

Severe damage to one-story light steel frame buildings was equally extensive at the two cities; the area was 3.3 square miles at Nagasaki and 3.4 square miles at Hiroshima. Heavy steel frame buildings could be studied only at Nagasaki, where they suffered structural damage over an area of 1.8 square miles.

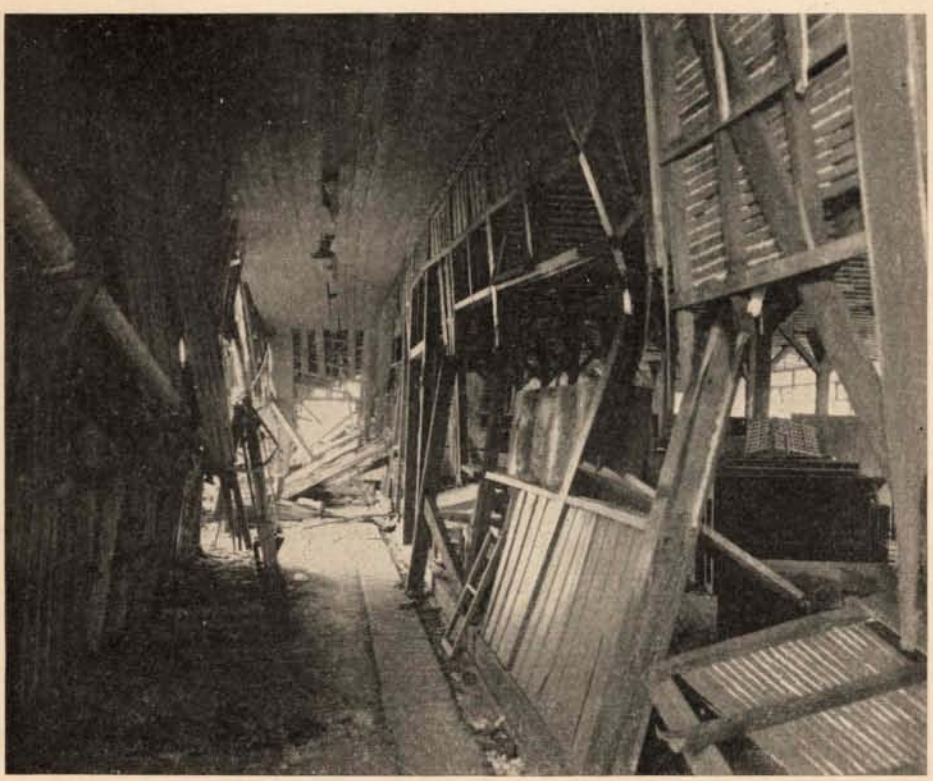
One-story brick buildings with load bearing walls were severely damaged within an area of 8.1 square miles at Nagasaki, and within an area of 6 square miles at Hiroshima. Multistory brick buildings, which were studied only at Hiroshima, were severely damaged within an area of 3.6 square miles.

Wood domestic buildings were severely damaged within an area of 7.5 square miles at Nagasaki, and within an area of 6 square miles at Hiroshima. Wood frame industrial and commercial buildings, which were of inferior construction, were severely damaged within 9.9 square miles at Nagasaki, and 8.5 square miles at Hiroshima.

Maximum blast pressures fall off very rapidly as the distance from the detonation increases. In the two bombed cities, thus, reinforced concrete buildings of good construction were structurally damaged only when within a few hundred feet of ground zero. Indeed, ground zero itself was too distant from air zero for the earthquake-resistant buildings to be collapsed. It is the opinion of the Survey's engineers that at Hiroshima more thorough destruction near ground zero, without significant loss in the scope of destruction, could have been achieved had the bomb been detonated at a lower altitude.

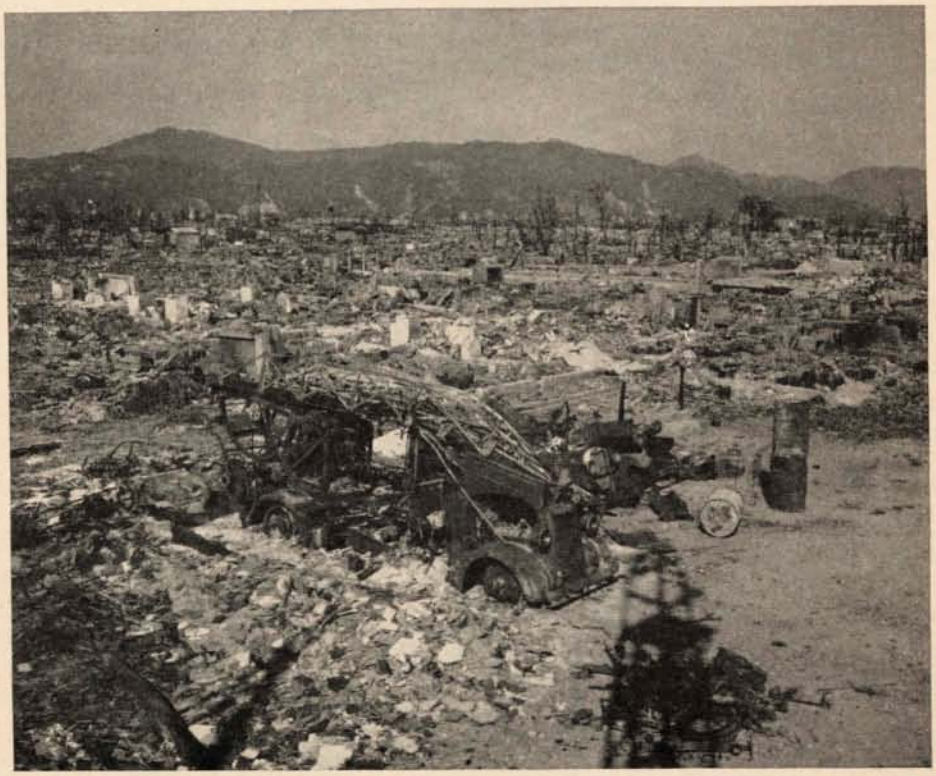


FIRE FRINGE. 8,200 feet from ground zero at Nagasaki, the old police station was completely gutted by fire. Hills protected houses on the right from blast, and fire did not spread to them (Japanese photo).



BLAST BUCKLED THE COLUMNS of this wood frame building, beyond the fire fringe at Hiroshima (7,600 feet from ground zero).

WRECKAGE IN NAGASAKI STREETCAR TERMINAL 1,500 feet north of ground zero. Streetcar in center was blown about 6 feet by the blast (Japanese photo).



THE HIROSHIMA FIRE DEPARTMENT lost its only aerial ladder truck when the west side main fire station was destroyed by blast and fire, 4,000 feet from ground zero (Japanese photo).

E. THE ATOMIC BOMB COMPARED WITH OTHER WEAPONS

In comparing the atomic bomb with other weapons, it is well to remember the importance of the height at which it exploded. Because of this distance from the targets, the atomic bombs did not exert at any point in Hiroshima or Nagasaki the high instantaneous peak pressures of even small high explosive bombs. For example, a single 100-pound bomb exploding at ground level exerts a higher blast pressure over an area of 1,000 square feet (for about 18 feet around its point of detonation) than did the atomic bomb at any point in either city.

That fact will place comparisons of the radii of effectiveness in the proper perspective. Even at the heights from which the atomic bomb was exploded in Japan, its blast effects were on a new scale because the duration of the blast was long compared to that of high explosive bombs. To take only one example: At Nagasaki, brick buildings suffered structural damage within a radius averaging 6,000 feet from ground zero. Comparable damage would be done by a 500-pound high explosive bomb burst at ground level for a radius of 55 feet; by a 1,000-pound bomb for 80 feet; by a 1-ton bomb for 110 feet; and by a 2-ton bomb for 200 feet. A hypothetical 10-ton blockbuster (only 10-ton penetrating bombs have actually been used) could be expected to achieve equivalent damage over a radius of 400 feet. The area of effectiveness of the air-burst atomic bomb against brick buildings thus ranged from 15,000 times as great as that for a 500-pound bomb to 225 times as great as that for the imaginary 10-ton blockbuster.

A simple table shows most strikingly the comparison between the striking forces needed for atomic and for conventional raids. Against the two atomic attacks can be set the data for the most effective single urban attack, that on Tokyo on 9 March 1945, and the average effort and results from the Twentieth Air Force's campaign against Japanese cities:

	Effort and results			
	Hiroshima	Nagasaki	Tokyo	Average of 93 urban attacks
Planes	1	1	279	173
Bomb load	[1] 1	[1] 1	[2] 1,667	[2] 1,129
Population density per square mile	35,000	65,000	130,000	[3]
Square miles destroyed	4.7	1.8	15.8	1.8
Killed and missing	70/80,000	35/40,000	83,600	1,850
Injured	70,000	40,000	102,000	1,830
Mortality rate per square mile destroyed	15,000	20,000	5,300	1,000
Casualty rate per square mile	32,000	43,000	11,800	2,000

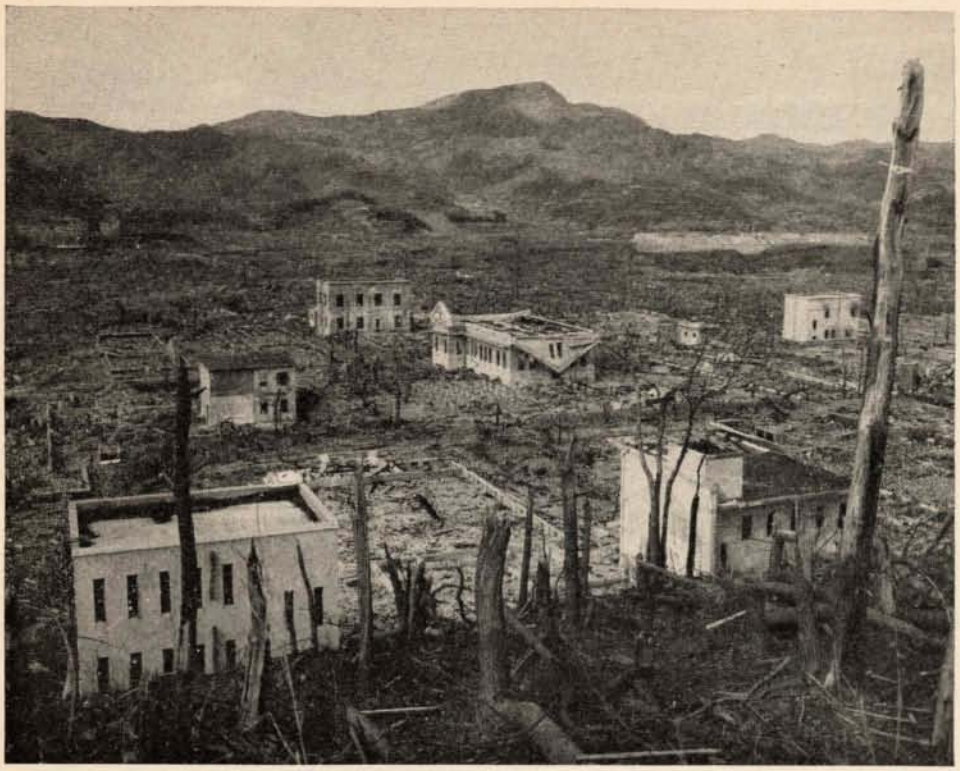
[1] Atomic. [2] Tons. [3] Unknown.

What stands out from this compilation, even more than the extent of the destruction from a single concentrated source, is the unprecedented casualty rate from the combination of heat, blast, and gamma rays from the chain reaction.

On the basis of the known destructiveness of various bombs computed from the war in Europe and the Pacific and from tests, the Survey has estimated the striking force that would have been necessary to achieve the same destruction at Hiroshima and Nagasaki. To cause physical damage equivalent to that caused by the atomic bombs, approximately 1,300 tons of bombs (one-fourth high explosives and three-fourths incendiaries) at Hiroshima and 600 tons (three-fourths high explosives and one-fourth incendiary) would have been required at Nagasaki—in the target area. To place that many bombs in the target area, assuming daylight attacks under essentially the same conditions of weather and enemy opposition that prevailed when the atomic bombs were dropped, it is estimated that 1,600 tons of bombs would have had to be dropped at Hiroshima and 900 tons at Nagasaki. To these bomb loads would have had to be added a number of tons of antipersonnel fragmentation bombs to inflict comparable casualties. These would add about 500 tons at Hiroshima and 300 tons at Nagasaki. The total bomb loads would thus be 2,100 tons at Hiroshima (400 HE, 1,200 IB) and 1,200 tons (675 HE, 225 IB) at Nagasaki. With each plane carrying 10 tons, the attacking force required would have been 210 B–29s at Hiroshima and 120 B–29s at Nagasaki.

It should be kept in mind, however, that the area of damage at Nagasaki does not represent the full potential effectiveness of the atomic bomb used there. The damage was limited by the small size of the rather isolated section of the city over which the bomb exploded. Had the target been sufficiently large, with no sections protected by intervening hills, the area of damage would have been about five times as large. An equivalent bomb load which would correspond to the destructive power of the Nagasaki bomb rather than the imperfect results achieved would approximate 2,200 tons of high explosives and incendiaries for physical damage plus 500 tons of fragmentation bombs for casualties, a total of 270 B–29 loads of 10 tons each.

DESTRUCTION OF BUILDINGS WITH BRICK LOAD BEARING WALLS. Note how brick debris lies inside wall facing blast, at remains of a barracks at the Japanese Army Divisional Grounds, 4,200 feet from ground zero at Hiroshima. The Koa Fire Insurance Co., 1,300 feet from ground zero, is completely destroyed except for the heavy walls of the vault.



REINFORCED CONCRETE BUILDINGS STILL STAND—but note how the interiors, as in the operating room of the Nagasaki University Hospital (2,200 feet from ground zero), are burnt out. Fire has consumed the floor, the balcony, and all seats, and distorted the metal railings and pipe.

IV. SIGNPOSTS

A. THE DANGER

The Survey's investigators, as they proceeded about their study, found an insistent question framing itself in their minds: "What if the target for the bomb had been an American City?" True, the primary mission of the Survey was to ascertain the facts just summarized. But conclusions as to the meaning of those facts, for citizens of the United States, forced themselves almost inescapably on the men who examined thoughtfully the remains of Hiroshima and Nagasaki. These conclusions have a different sort of validity from the measurable and ponderable facts of preceding sections, and therefore they are presented separately. They are not the least important part of this report, however, and they are stated with no less conviction.

No two cities, whether in Japan or the United States, are exactly alike. But the differences in terrain, layout and zoning, density, and type of construction can be allowed for one by one; when that is done, comparisons become possible. The most striking difference between American and Japanese cities is in residential districts: what happened to typical Japanese homes is not directly applicable to American residential districts. But in Japanese cities were many brick and wood frame buildings of Western or similar design and of good workmanship. It was the opinion of the Survey's engineers, with their professional familiarity with American buildings, that these Japanese buildings reacted to the bomb much as typical American buildings would have. And these buildings were exceedingly vulnerable: multi-story brick buildings with load-bearing walls were destroyed or seriously damaged over an area of 3.6 square miles at Hiroshima, while similar one-story brick buildings were destroyed or seriously damaged within an area of 6 square miles. Wood frame buildings built as industrial or commercial shops suffered similar damage in an area of over 8 miles, while Japanese residences were destroyed or seriously damaged within an area of 6 square miles. This was at Hiroshima, where the less powerful bomb was used!

These figures indicate what would happen to typical wood, brick, and stucco structures in American cities. Modern reinforced concrete and steel frame buildings would fare better here—as they did in Japan. But the following table shows how American cities are built, and how few buildings are of blast-resistant construction.

City	Types of structures by exterior material (United States cities)				
	Total structures reported	Wood	Brick	Stucco	Other materials[1]
New York	591,319	236,879	299,482	41,661	13,297
Washington	156,359	48,971	95,939	5,764	5,685
Chicago	382,628	131,148	238,959	5,797	6,724
Detroit	267,677	165,488	94,333	1,923	5,933
San Francisco	105,180	61,172	2,334	40,902	722

Source: Sixteenth Census of the United States (1940), vol. II.
[1] Includes blast-resistant buildings.

The overwhelming bulk of the buildings in American cities could not stand up against an atomic bomb bursting a mile or a mile and a half from them.

And the people? We must not too readily discount the casualty rate because of the teeming populations of congested Japanese cities. American cities, too, have their crowded slums, and in addition tend to build vertically so that the density of the population is high in a given area even though each apartment dweller may have more living space than his Japanese equivalent.

Most of the population densities in this table are merely averages for people within a city limits. Most meaningful, therefore, are the figures for the central areas of Hiroshima and Nagasaki, and for the boroughs of New York. The casualty rates at Hiroshima and Nagasaki, applied to the massed inhabitants of Manhattan, Brooklyn, and the Bronx, yield a grim conclusion. These casualty rates, it must never be forgotten, result from the first atomic bombs to be used and from bombs burst

DAMAGE TO MACHINE TOOLS was usually indirect. At the Mitsubishi Steel and Arms Works, 4,200 feet from ground zero at Nagasaki, many closely packed machines escaped serious damage from collapsing roof trusses, but were exposed to the weather. Other machines were torn from their foundations by collapsing steel members.

at considerable distances above the ground. Improved bombs, perhaps detonated more effectively, may well prove still more deadly.

City	Population densities United States and Japanese cities		Population density per sq. mile
	Population	Area sq. mi.	
New York	7,492,000	322.8	23,200
Manhattan (day)	3,200,000	22.2	145,000
Manhattan (night)	1,689,000	22.2	76,000
Bronx	1,493,700	41.4	34,000
Brooklyn	2,792,600	80.9	34,200
Queens	1,340,500	121.1	11,000
Staten Island	176,200	57.2	3,000
Washington	663,091	61.4	11,000
Chicago	3,396,808	206.7	16,500
Detroit	1,623,452	137.9	11,750
San Francisco	634,536	44.6	14,250
Hiroshima	[1] 340,000	26.5	12,750
Center of city	[2] 140,000	4.0	35,000
Nagasaki	[1] 250,000	35	7,000
Built-up area	[2] 220,000	3.4	65,000

[1] Prewar.
[2] As of 1 Aug. 45.

Source: New York: Fortune, July 1939—Other United States cities: Sixteenth Census of the United States (1940).

B. WHAT WE CAN DO ABOUT IT

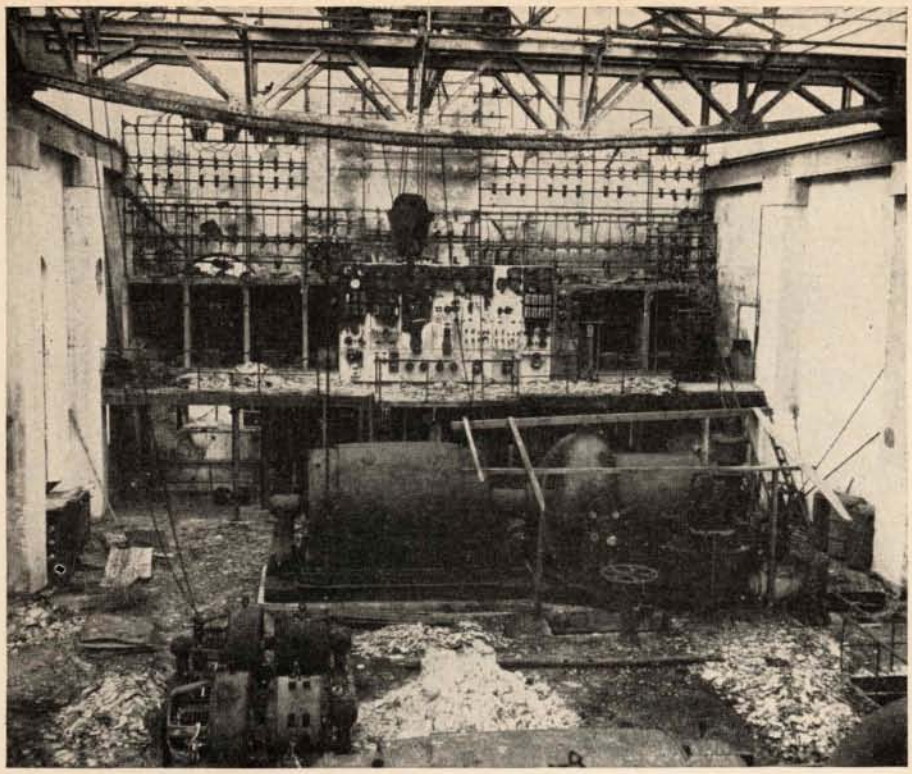
The danger is real—of that, the Survey's findings leave no doubt. Scattered through those findings, at the same time, are the clues to the measures that can be taken to cut down potential losses of lives and property. These measures must be taken or initiated *now*, if their cost is not to be prohibitive. But if a policy is laid down, well in advance of any crisis, it will enable timely decentralization of industrial and medical facilities, construction or blueprinting of shelters, and preparation for life-saving evacuation programs. The almost unprotected, completely surprised cities of Japan suffered maximum losses from atomic bomb attack. If we recognize in advance the possible danger and act to forestall it, we shall at worst suffer minimum casualties and disruption.

Since modern science can be marshalled for the defense as well as the attack, there is reason to hope that protective weapons and techniques will be improved. Even protective devices and vigilance, however, cannot be perfect guards against surprise or initial attack, or against the unlimited choices of targets offered an enemy through the range and speed of modern weapons. In our planning for the future, if we are realistic, we will prepare to minimize the destructiveness of such attacks, and so organize the economic and administrative life of the Nation that no single or small group of successful attacks can paralyze the national organism. The foregoing description of the effectiveness of the atomic bomb has shown clearly that, despite its awesome power, it has limits of which wise planning will take prompt advantage.

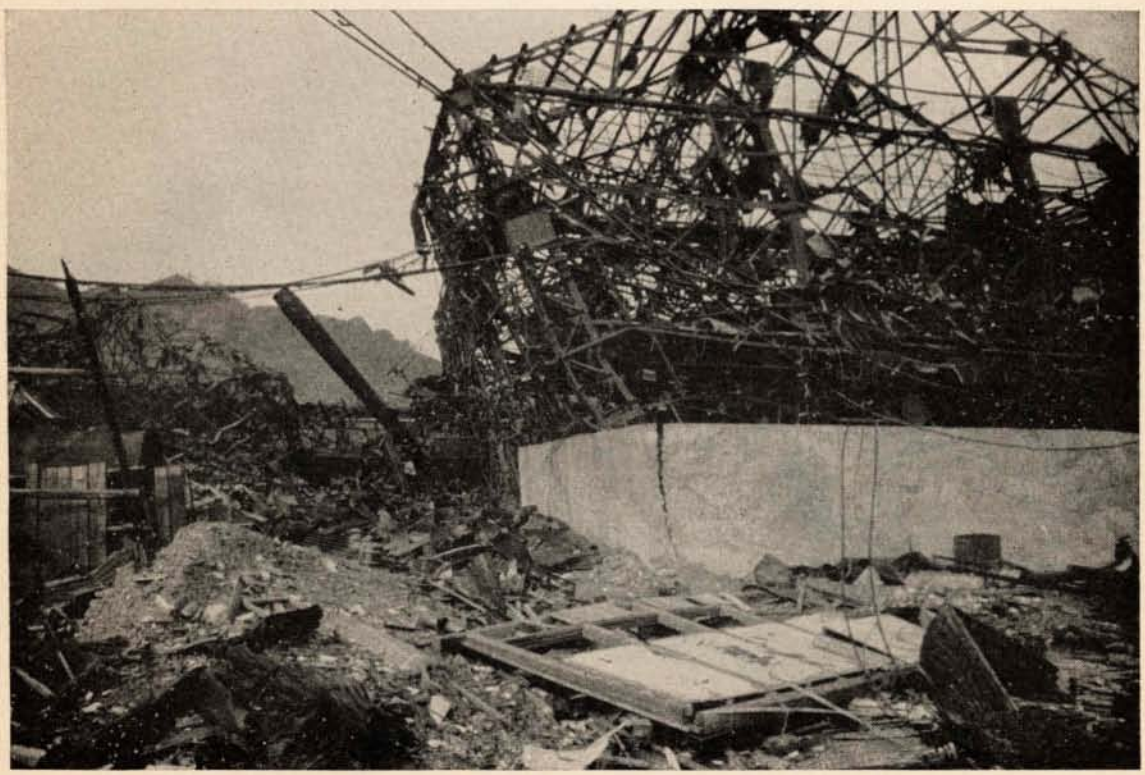
1. *Shelters.*—The most instructive fact at Nagasaki was the survival, even when near ground zero, of the few hundred people who were properly placed in the tunnel shelters. Carefully built shelters, though unoccupied, stood up well in both cities. Without question, shelters can protect those who get to them against anything but a direct hit. Adequate warning will assure that a maximum number get to shelters.

Analysis of the protection of survivors within a few hundred feet of ground zero shows that shielding is possible even against gamma rays. At Hiroshima, for example, persons in a concrete building 3,600 feet from ground zero showed no clinical effects from gamma radiation, but those protected only by wooden buildings at a similar distance suffered from radiation disease. The necessary thickness varies with the substance and with the distance from the point of detonation. Adequate shelters can be built which will reduce substantially the casualties from radiation.

Men arriving at Hiroshima and Nagasaki have been constantly impressed by the shells of reinforced concrete buildings still rising above the rubble of brick and stone or the ashes of wooden buildings. In most cases gutted by fire or stripped of partitions and interior trim, these buildings have a double lesson for us. They show, first, that it is possible without excessive expense to erect buildings which will satisfactorily protect their contents at distances of about 2,000 feet or more from a bomb of the types so far employed. Construction of such buildings would be similar to earthquake resistant construction, which California experience indicates would cost about 10 percent to 15 percent more than conventional construction. Even against more powerful bombs or against near misses, such construction would diminish damage. Second, the internal damage illustrates the danger from interior details and construction which result in fire or flying debris in otherwise sound buildings. The elimination of combustible interiors and the provision of full-masonry partition



HEAVY ELECTRICAL EQUIPMENT such as this turbogenerator at Minami Sendamachi substation 7,700 feet from ground zero at Hiroshima, often survived the explosion.



NAGASAKI. Steel-framed building about 4,000 feet south of ground zero in Mitsubishi Steel and Arms Works distorted to grotesque shape by blast of bomb.

NAGASAKI SHELTERS. Tunnel shelters in the hillside, such as the ones pictured (very close to ground zero), protected the few occupants from blast, heat, and radiation.

HIROSHIMA EARTH-AND-POLE AIR-RAID SHELTER. This simple shelter is undamaged by fire and blast 5,000 feet northeast of ground zero, though surrounding buildings have been destroyed (Japanese photo, 10 August 1945).

walls, fire-resistive stair and elevator enclosures, and fire division walls would localize fires. Avoidance of glass, tile, or lath and plaster on wood stud would cut down damage from flying debris. The studies of the Physical Damage Division of the Survey support such recommendations and include many others.

The survival of sheltered sections of Nagasaki suggests forcefully the use that can be made of irregular terrain. Uneven ground reduces the spread and uniformity of blast effect. Terrain features such as rivers and parks afford natural firebreaks and avenues of escape.

2. *Decentralization.*—Hiroshima and Nagasaki were chosen as targets because of their concentration of activities and population. The population density of 45,000 or more per square mile of built-up area explains in part the high casualty rate. Significant therefore is the fact that deaths at Nagasaki, despite the greater population density, were only one-half those at Hiroshima: the difference can be assigned in the main to the separation of the dispersed built-up pockets at Nagasaki, in contrast to the uniform concentration of the inhabitants in the heart of Hiroshima. The Nagasaki bomb thus dissipated much of its energy against hills, water, or unoccupied areas, while the Hiroshima bomb achieved almost optimum effect.

The fate of industries in both cities again illustrates the value of decentralization. All major factories in Hiroshima were on the periphery of the city—and escaped serious damage; at Nagasaki, plants and dockyards at the southern end of the city were left intact, but those in the valley where the bomb exploded were seriously damaged. So spread out were the industries in both cities that no single bomb could have been significantly more effective than the two actually dropped.

Medical facilities, crowded into the heart of the city rather than evenly spread through it, were crippled or wiped out by the explosion. Only the previous removal of some stocks of medical supplies from Hiroshima to outlying communities, and the bringing in of aid, enabled the limited medical attention of the first few days.

These results underline those in conventional area raids in Germany, where frequently the heart of a city was devastated while peripheral industries continued to produce and where (particularly in Hamburg) destruction of medical facilities just at the time of greatest need hampered care of wounded.

The similar peril of American cities and the extent to which wise zoning has diminished it differ from city to city. Though a reshaping and partial dispersal of the national centers of activity are drastic and difficult measures, they represent a social and military ideal toward which very practical steps can be taken once the policy has been laid down. In the location of plants, administrative headquarters, and hospitals particularly, the value of decentralization is obvious, and can be obtained cheaply if the need is foreseen. For example, by wise selection of dispersed sites, the present hospital building program of the Veterans' Administration could be made to lessen our congestion without additional cost.

Reserve stocks of critical materials and of such products as medical supplies should be kept on hand. This principle of maintaining reserves applies also to the capital equipment of the country. Key producing areas must not be served by a single source of power or channel of transportation. Indispensable materials must not come from processing plants of barely adequate capacity. Production of essential manufactured goods—civilian and military—must not be confined to a few or to geographically centralized plants. And the various regions of the country should be encouraged to approach balanced economic development as closely as is naturally possible. An enemy viewing our national economy must not find bottlenecks which use of the atomic bomb could choke off to throttle our productive capacity.

3. *Civilian defense.*—Because the scale of disaster would be certain to overwhelm the locality in which it occurs, mutual assistance organized on a national level is essential. Such national organization is by no means inconsistent with decentralization; indeed, it will be aided by the existence of the maximum number of nearly self-sustaining regions whose joint support it can coordinate. In addition, highly trained mobile units skilled in and equipped for fire fighting, rescue work, and clearance and repair should be trained for an emergency which disrupts local organization and exceeds its capability for control.

Most important, a national civilian defense organization can prepare now the plans for necessary steps in case of crisis. Two complementary programs which should be worked out in advance are those for evacuation of unnecessary inhabitants

THIS STEEL FRAME BUILDING, 2,000 feet from ground zero at Hiroshima, had its first-story columns buckle away from the blast, dropping the second story to the ground. Combustibles were destroyed by fire.

COLLAPSE OF REINFORCED CONCRETE BUILDING. Chugoku Coal Distribution Control Co., 700 feet from ground zero at Hiroshima.

from threatened urban areas, and for rapid erection of adequate shelters for people who must remain.

4. *Active defense.*—Protective measures can substantially reduce the degree of devastation from an atomic bomb and the rate of casualties. Yet if the possibility of atomic attack on us is accepted, we must accept also the fact that no defensive measures alone can long protect us. At best they can minimize our losses and preserve the functioning of the national community through initial or continuing partial attack. Against full and sustained attacks they would be ineffectual palliatives.

As defensive weapons, atomic bombs are useful primarily as warnings, as threats of retaliation which will restrain a potential aggressor from their use as from the use of poison gas or biological warfare. The mission of active defense, as of passive defense, is thus to prevent the surprise use of the atomic bomb from being decisive. A wise military establishment will make sure—by dispersal, concealment, protection, and constant readiness of its forces—that no single blow or series of blows from an enemy can cripple its ability to strike back in the same way or to repel accompanying attacks from other air, ground, or sea forces. The measures to enable this unrelaxing state of readiness are not new; only their urgency is increased. Particularly is this true of the intelligence activities on which informed decisions and timely actions depend.

The need for research is not limited to atomic energy itself, but is equally important in propellants, detection devices, and other techniques of countering and of delivering atomic weapons. Also imperative is the testing of the weapon's potentialities under varying conditions. The coming Operation Crossroads, for example, will give valuable data for defining more precisely what is already known about the atomic bomb's effectiveness when air-burst; more valuable, however, will be tests under new conditions, to provide sure information about detonations at water level or under water, as well as underground. While prediction of effects under differing conditions of detonation may have a high degree of probability, verified knowledge is a much better basis for military planning.

5. *Conclusion.*—One further measure of safety must accompany the others. To avoid destruction, the surest way is to avoid war. This was the Survey's recommendation after viewing the rubble of German cities, and it holds equally true whether one remembers the ashes of Hiroshima or considers the vulnerability of American cities.

Our national policy has consistently had as one of its basic principles the maintenance of peace. Based on our ideals of justice and of peaceful development of our resources, this disinterested policy has been reinforced by our clear lack of anything to gain from war—even in victory. No more forceful arguments for peace and for the international machinery of peace than the sight of the devastation of Hiroshima and Nagasaki have ever been devised. As the developer and exploiter of this ominous weapon, our nation has a responsibility, which no American should shirk, to lead in establishing and implementing the international guarantees and controls which will prevent its future use.

UNITED STATES STRATEGIC BOMBING SURVEY

European War

LIST OF REPORTS

The following list of studies is a bibliography of completed reports resulting from the German survey. Reports numbers 1, 2, and 3 can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Permission to examine the remaining reports may be had by writing to the headquarters of the Survey at Gravelly Point, Washington 25, D. C.

1 The United States Strategic Bombing Survey: Summary Report (European War)
2 The United States Strategic Bombing Survey: Over-all Report (European War)
3 The Effects of Strategic Bombing on the German War Economy

AIRCRAFT DIVISION

(By Division and Branch)

4 Aircraft Division Industry Report
5 Inspection Visits to Various Targets (Special Report)

Airframes Branch

6 Junkers Aircraft and Aero Engine Works, Dessau, Germany
7 Erla Maschinenwerke G m b H, Heiterblick, Germany
8 A T G Maschinenbau, G m b H, Leipzig (Mockau), Germany
9 Gothaer Waggonfabrik, A G, Gotha, Germany
10 Focke Wulf Aircraft Plant, Bremen, Germany
11 Messerschmitt A G, Augsburg, Germany — Over-all Report; Part A; Part B; Appendices I, II, III
12 Dornier Works, Friedrichshafen & Munich, Germany
13 Gerhard Fieseler Werke G m b H, Kassel, Germany
14 Wiener Neustaedter Flugzeugwerke, Wiener Neustadt, Austria

Aero Engines Branch

15 Bussing NAG Flugmotorenwerke G m b H, Brunswick, Germany
16 Mittel-Deutsche Motorenwerke G m b H, Taucha, Germany
17 Bavarian Motorworks Inc., Eisenach & Durrenhof, Germany
18 Bayerische Motorenwerke A G (BMW) Munich, Germany
19 Henschel Flugmotorenwerke, Kassel, Germany

Light Metal Branch

20 Light Metals Industry of Germany — Part I, Aluminum; Part II, Magnesium
21 Vereinigte Deutsche Metallwerke, Hildesheim, Germany
22 Metallgussgesellschaft G m b H, Leipzig, Germany
23 Aluminiumwerk G m b H, Plant No. 2, Bitterfeld, Germany
24 Gebrueder Giulini G m b H, Ludwigshafen, Germany
25 Luftschiffbau Zeppelin G m b H, Friedrichshafen on Bodensee, Germany
26 Wieland Werke A G, Ulm, Germany
27 Rudolph Rautenbach Leichtmetallgiessereien. Solingen, Germany
28 Lippewerke Vereinigte Aluminiumwerke A G, Lunen, Germany
29 Vereinigte Deutsche Metallwerke, Heddernheim, Germany
30 Duerener Metallwerke A G, Duren Wittenau-Berlin & Waren, Germany

AREA STUDIES DIVISION

31 Area Studies Division Report
32 A Detailed Study of the Effects of Area Bombing on Hamburg
33 A Detailed Study of the Effects of Area Bombing on Wuppertal
34 A Detailed Study of the Effects of Area Bombing on Dusseldorf
35 A Detailed Study of the Effects of Area Bombing on Solingen
36 A Detailed Study of the Effects of Area Bombing on Remscheid
37 A Detailed Study of the Effects of Area Bombing on Darmstadt
38 A Detailed Study of the Effects of Area Bombing on Lubeck
39 A Brief Study of the Effects of Area Bombing on Berlin, Augsburg, Bochum, Leipzig, Hagen, Dortmund, Oberhausen, Schweinfurt, and Bremen

CIVILIAN DEFENSE DIVISION

40 Civilian Defense Division—Final Report
41 Cologne Field Report
42 Bonn Field Report
43 Hanover Field Report
44 Hamburg Field Report—Vol I, Text; Vol II, Exhibits
45 Bad Oldesloe Field Report

46 Augsburg Field Report
47 Reception Areas in Bavaria, Germany

EQUIPMENT DIVISION

Electrical Branch

48 German Electrical Equipment Industry Report
49 Brown Boveri et Cie, Mannheim Kafertal, Germany

Optical and Precision Instrument Branch

50 Optical and Precision Instrument Industry Report

Abrasives Branch

51 The German Abrasive Industry
52 Mayer and Schmidt, Offenbach on Main, Germany

Anti-Friction Branch

53 The German Anti-Friction Bearings Industry

Machine Tools Branch

54 Machine Tools & Machinery as Capital Equipment
55 Machine Tool Industry in Germany
56 Herman Kolb Co., Cologne, Germany
57 Collet and Engelhard, Offenbach, Germany
58 Naxos Union, Frankfort on Main, Germany

MILITARY ANALYSIS DIVISION

59 The Defeat of the German Air Force
60 V-Weapons (Crossbow) campaign
61 Air Force Rate of Operation
62 Weather Factors in Combat Bombardment Operations in the European Theatre
63 Bombing Accuracy, USAAF Heavy and Medium Bombers in the ETO
64 Description of RAF Bombing

MORALE DIVISION

Medical Branch

65 The Effect of Bombing on Health and Medical Care in Germany

MUNITIONS DIVISION

Heavy Industry Branch

66 The Coking Industry Report of Germany
67 Coking Plant Report No. 1, Sections A, B, C, & D
68 Gutehoffnungshuette, Oberhausen, Germany
69 Friedrich-Alfred Hutte, Rheinhausen, Germany
70 Neunkirchen Eisenwerke A G, Neunkirchen, Germany
71 Reichswerke Hermann Goering A G, Hallendorf, Germany
72 August Thyssen Huette A G, Hamborn, Germany
73 Friedrich Krupp A G, Borbeck Plant, Essen, Germany
74 Dortmund Hoerder Huettenverein, A G, Dortmund, Germany
75 Hoesch A G, Dortmund, Germany
76 Bochumer Verein fuer Gusstahlfabrikation A G, Bochum, Germany

Motor Vehicles and Tanks Branch

77 German Motor Vehicles Industry Report
78 Tank Industry Report
79 Daimler Benz A G, Unterturkheim, Germany
80 Renault Motor Vehicles Plant, Billancourt, Paris
81 Adam Opel, Russelheim, Germany
82 Daimler Benz-Gaggenau Works, Gaggenau, Germany
83 Maschinenfabrik Augsburg-Nurnberg, Nurnberg, Germany
84 Auto Union A G, Chemnitz and Zwickau, Germany
85 Henschel and Sohn, Kassel, Germany
86 Maybach Motor Works, Friedrichshafen, Germany
87 Voigtlander Maschinenfabrik A G, Plauen, Germany
88 Volkswagenwerke, Fallersleben, Germany
89 Bussing NAG, Brunswick, Germany
90 Muehlenbau Industrie A G (Miag) Brunswick, Germany
91 Friedrich Krupp Grusonwerke, Magdeburg, Germany

Submarine Branch

92 German Submarine Industry Report
93 Maschinenfabrik Augsburg-Nurnberg A G, Augsburg, Germany
94 Blohm and Voss Shipyards, Hamburg, Germany
95 Deutschewerke A G, Kiel, Germany
96 Deutsche Schiff und Maschinenbau, Bremen, Germany
97 Friedrich Krupp Germaniawerft, Kiel, Germany
98 Howaldtswerke A G, Hamburg, Germany
99 Submarine Assembly Shelter, Farge, Germany
100 Bremer Vulkan, Vegesack, Germany

Ordnance Branch

101 Ordnance Industry Report
102 Friedrich Krupp Grusonwerke A G, Magdeburg, Germany
103 Bochumer Verein fuer Gusstahlfabrikation A G, Bochum, Germany
104 Henschel and Sohn, Kassel, Germany
105 Rheinmetall-Borsig, Dusseldorf, Germany
106 Hermann Goering Werke, Braunschweig, Hallendorf, Germany
107 Hannoverische Maschinenbau, Hanover, Germany
108 Gusstahlfabrik Friedrich Krupp, Essen, Germany

OIL DIVISION

109 Oil Division Final Report
110 Oil Division Final Report, Appendix
111 Powder, Explosives, Special Rockets and Jet Propellants, War Gases and Smoke Acid (Ministerial Report #1)
112 Underground and Dispersal Plants in Greater Germany
113 The German Oil Industry, Ministerial Report Team 78
114 Ministerial Report on Chemicals

Oil Branch

115 Ammoniakwerke Merseburg G m b H, Leuna, Germany—2 appendices
116 Braunkohle Benzin A G, Zeitz and Bohlen, Germany
Wintershall A G, Luetzkendorf, Germany
117 Ludwigshafen-Oppau Works of I G Farbenindustrie A G, Ludwigshafen, Germany
118 Ruhroel Hydrogenation Plant, Bottrop-Boy, Germany, Vol I and Vol II

119 Rhenania Ossag Mineraloelwerke A G, Harburg Refinery, Hamburg, Germany
120 Rhenania Ossag Mineraloelwerke A G, Grassbrook Refinery, Hamburg, Germany
121 Rhenania Ossag Mineraloelwerke A G, Wilhelmsburg Refinery, Hamburg, Germany
122 Gewerkschaft Victor, Castrop-Rauxel, Germany, Vol I & Vol II
123 Europaeische Tanklager und Transport A G. Hamburg, Germany
124 Ebano Asphalt Werke A G, Harburg Refinery, Hamburg, Germany
125 Meerbeck Rheinpreussen Synthetic Oil Plant—Vol I & Vol II

Rubber Branch

126 Deutsche Dunlop Gummi Co., Hanau on Main, Germany
127 Continental Gummiwerke, Hanover, Germany
128 Huels Synthetic Rubber Plant
129 Ministerial Report on German Rubber Industry

Propellants Branch

130 Elektro Chemischewerke, Munich, Germany
131 Schoenebeck Explosive Plant, Lignose Sprengstoff Werke G m b H, Bad Salzemen, Germany
132 Plants of Dynamit A G, Vormal, Alfred Nobel & Co, Troisdorf, Clausthal, Drummel and Duneberg, Germany
133 Deutsche Sprengchemie G m b H, Kraiburg, Germany

OVERALL ECONOMIC EFFECTS DIVISION

134 Overall Economic Effects Division Report
Gross National Product
Kriegs Eil Berichte
Herman Goering Works
Food and Agriculture
} Special papers which together comprise the above report

PHYSICAL DAMAGE DIVISION

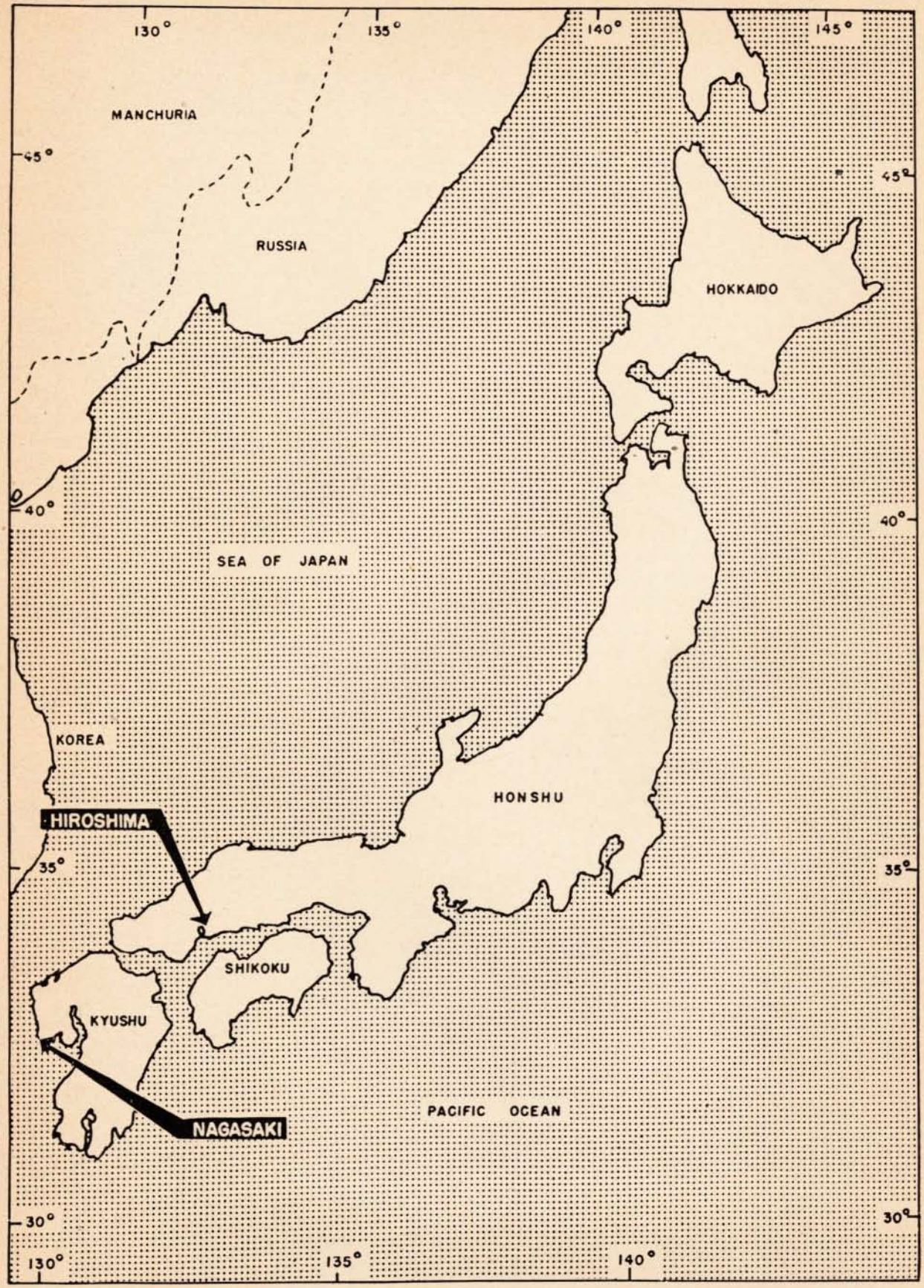
135 Villacoublay Airdrome, Paris, France
136 Railroad Repair Yards, Malines, Belgium
137 Railroad Repair Yards, Louvain, Belgium
138 Railroad Repair Yards, Hasselt, Belgium
139 Railroad Repair Yards, Namur, Belgium
140 Submarine Pens, Brest, France
141 Powder Plant, Angouleme, France
142 Powder Plant, Bergerac, France
143 Coking Plants, Montigny & Liege-Belgium
144 Fort St. Blaise Verdun Group, Metz, France
145 Gnome et Rhone, Limoges, France
146 Michelin Tire Factory, Clermont-Ferrand, France
147 Gnome et Rhone Aero Engine Factory, Le Mans, France
148 Kugelfisher Bearing Ball Plant, Ebelspach, Germany
149 Louis Breguet Aircraft Plant, Toulouse, France
150 S. N. C. A. S. E. Aircraft Plant, Toulouse, France
151 A. I. A. Aircraft Plant, Toulouse, France
152 V Weapons in London
153 City Area of Krefeld
154 Public Air Raid Shelters in Germany
155 Goldenberg Thermal Electric Power Station, Knapsack, Germany
156 Brauweiler Transformer & Switching Station, Brauweiler, Germany
157 Storage Depot, Nahbollenbach, Germany
158 Railway and Road Bridge, Bad Munster, Germany
159 Railway Bridge, Eller, Germany
160 Gustloff-Werke Weimar, Weimar, Germany
161 Henschel and Sohn G m b H, Kassel, Germany
162 Area Survey at Pirmasens, Germany
163 Hanomag, Hanover, Germany
164 M A N Werke Augsburg, Augsburg, Germany
165 Friedrich Krupp A G, Essen, Germany
166 Erla Maschinenwerke, G m b H, Heiterblick, Germany
167 A T G Maschinenbau G m b H, Mockau, Germany
168 Erla Maschinenwerke G m b H, Mockau, Germany
169 Bayerischa Motorenwerke Durrerhoff, Germany
170 Mittel-Deutsche Motorenwerke G m b H, Taucha, Germany
171 Submarine Pens Deutsche-Werft, Hamburg, Germany
172 Multi-Storied Structures, Hamburg, Germany
173 Continental Gummiwerke, Hanover, Germany
174 Kassel Marshalling Yards, Kassel, Germany
175 Ammoniskwerke, Mersburg-leuna, Germany
176 Brown Boveri et Cie, Mannheim, Kafertal, Germany
177 Adam Opel A G, Russelheim, Germany
178 Daimler-Benz A G, Unterturkheim, Germany
179 Valentin Submarine Assembly, Farge, Germany
180 Volkswaggonwerke, Fallersleben, Germany
181 Railway Viaduct at Bielefeld, Germany
182 Ship Yards Howaldtswerke, Hamburg, Germany
183 Blohm and Voss Shipyards, Hamburg, Germany
184 Daimler-Benz A G, Mannheim, Germany
185 Synthetic Oil Plant, Meerbeck-Hamburg, Germany
186 Gewerkschaft Victor, Castrop-Rauzel, Germany
187 Klockner Humblolt Deutz, Ulm, Germany
188 Ruhroel Hydrogenation Plant, Bettrop-Boy, Germany
189 Neukirchen Eisenwereke A G, Neukirchen, Germany
190 Railway Viaduct at Altenbecken, Germany
191 Railway Viaduct at Arnsburg, Germany
192 Deurag-Nerag Refineries, Misburg, Germany
193 Fire Raids on German Cities
194 I G Farbenindustrie, Ludwigshafen, Germany, Vol I & Vol II
195 Roundhouse in Marshalling Yard, Ulm, Germany
196 I G Farbenindustrie, Leverkusen, Germany
197 Chemische-Werke, Huels, Germany
198 Gremberg Marshalling Yard, Gremberg, Germany
199 Locomotive Shops and Bridges at Hamm, Germany

TRANSPORTATION DIVISION

200 Transportation Division Report
201 Rail Operations Over the Brenner Pass
202 Effects of Bombing on Railroad Installations in Regensburg, Nurnberg and Munich Divisions.
203 German Locomotive Industry During the War
204 Wehrmacht Traffic Over the German Railroads

UTILITIES DIVISION

205 German Electric Utilities Industry Report
206 1 to 10 in Vol I "Utilities Division Plant Reports"
207 11 to 20 in Vol II "Utilities Division Plant Reports"
208 21 Rheinische-Westfalische Elektrizitätswerk A G


130°
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KOREA
HONSHU
HIROSHIMA
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SHIKOKU
KYUSHU
PACIFIC OCEAN
NAGASAKI
30°