# Fire Effects of Bombing Attacks

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## ILLUSTRATIONS



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# Introduction

THE enormous effectiveness of fire as a weapon of war was demonstrated in World War II. Structural damage caused by fire accounted for 80 percent of the total damage to the cities attacked by airborne weapons. The great fire attacks on the cities of Germany and Japan were scientifically planned with emphasis placed on the susceptibility of the target and the type and quantity of munitions necessary to produce maximum damage. The lessons learned from these attacks and later from the atomic bomb attacks on Hiroshima and Nagasaki should provide valuable guidance to planners in designing measures to minimize the effects of fire damage to American cities in any future war.

It can be assumed that no area in the United States will be immune from possible attack because of its situation alone. This assumption, and the knowledge that destruction or immobilization of a nation's vital industry will destroy its capacity to defend itself, makes it reasonable to predict that highly concentrated areas of vital industry and population will be the most likely targets. While the type of weapons an enemy would use cannot be known, the extent of fire from the action of such weapons will be influenced by the characteristics of the target at the time of the attack.

The efficacy of the fire-fighting services as a major arm of civil defense must be determined by the degree to which they will be able to lessen the fire-damage effects of bombing. The term "fire services" as used here includes all elements and agencies devoted to fire protection and fire fighting on local, State, and Federal levels. If no other civil defense machinery were available, local fire departments would fight fires, perform rescue, handle victims of fire or explosions, and carry on salvage and restoration. The magnitude of the problem in wartime will restrict the duties of fire-fighting services to the fire-fighting field. Other peacetime functions will be delegated to separate civil defense agencies.

This study is designed to guide and assist civil defense fire-fighting services in preparing to combat mass fires in time of war. Section I presents a summary of the mass of data on bombing attacks in World War II taken from the reports of the U. S. Strategic Bombing Survey and presents problems of extinguishing and controling mass fires resulting from bombing. Section II discusses the principal factors of susceptibility characteristic of all cities and suggests a method of appraising them for the purpose of defending American municipalities against mass fires following attack from the air.

Manuals will be published later describing techniques for dealing with fire warfare as considered in this study.

SECTION I

# Fire Warfare in World War II

## FIRE WARFARE ON GERMAN CITIES

Complete appraisal of the fire damage in German cities may never be made. The best figures for total damage due to high-explosive and incendiary bombs were compiled from aerial surveys made by the British Air Ministry. Although admittedly incomplete, records of the principal attacks on most cities were included. Of the 49 cities studied, 39 percent of the individual dwelling units (2,164,800 out of a total of 5,554,500) were seriously damaged.

Both high-explosive and incendiary bombs were used in the great attacks on German targets by the U. S. Army Air Force and the Royal Air Force. The high-explosive bombs varied in size from 100 to 2,000 pounds (with heavier bombs for special targets). The incendiary bombs varied from 4 to 100 pounds (with some 500-pound bombs used on industrial installations) and were of two general types, namely: (1) Those in which the container was combustible and served as incendiary material, and (2) those in which the case was merely a container capable of placing the incendiary filling at the desired place in the target.

In the principal city attacks the total load of bombs dropped consisted of an approximately equal weight of high explosives and incendiaries. High-explosive bombs deterred fire fighting, disrupted communications, broke water-main networks, created road blocks, opened up buildings, broke windows, and displaced roofing. In some places they caused fires, but this was a secondary and relatively minor factor. The incendiaries started most of the fires.

Bomb loads of 1,000 to 2,000 tons were dispatched over German cities in one night. A total of over 7,000 tons was dropped on Hamburg, and an even heavier bomb load was dropped on Dresden in the closing days of the war. In contrast, the heaviest single attack on an English city was 457 tons of incendiary and high-explosive bombs dropped on London on the night of April 16–17, 1941. These figures show that the German attacks on England were relatively light despite the great damage they caused.

### The Pattern of German Cities

The central portions of German cities had a building density (the ratio of roof area to ground area) of approximately 40 percent and made excellent targets for incendiary attack. The presence of masonry party walls between individual building units prevented much free spread of fire from building to building. The buildings destroyed by fire (with the exception of those involved in "fire storms," described in the next section) were hit by bombs rather than ignited by fire spread from other buildings.

The average German city contained at its core a medieval town which was closely built up with narrow and winding streets. The buildings were 3 to 5 stories high depending on the size of the city and averaged about 1,500 square feet in area. They had several tiers of attics strongly framed in timber with roof ridges at right angles to the street.

An eighteenth century town was built around the "old town." This had a rectangular street pattern, and buildings were 3 to 6 stories in height. The buildings were somewhat larger, but only a few were over 3,000 square feet. Most of these buildings had masonry walls and tile or slate roofs on wooden battens. Heavy wooden "pugged" floors were characteristic. These floors had a layer of cinders or other inert matter between the ceiling and the floor finish above. Each building unit was separated from the adjacent buildings by a common wall which was sometimes parapeted and sometimes built just on the underside of the roof. There were often small "backyard" industrial buildings in the center of these blocks.

The more modern sections of the city were built around the eighteenth century town with wide streets and buildings of modern construction. In these modern buildings, areas were small, wood floors were common, and roof-supporting members were wood.

The United States Strategic Bombing Survey made ground studies of six cities where fire damage was extensive: Hamburg, Kassel, Wuppertal, Darmstadt, Pirmasens, and Krefeld.

The attacks on Hamburg (population 1,760,000) are illustrative and present a picture which was common in varying degrees in other German cities. Four major Royal Air Force attacks in July and August of 1943 destroyed 55 to 60 percent of the city. Of the physical destruction 75 to 80 percent was caused by fire. An area of some 30 square miles was damaged which included 12½ square miles completely burned out. Some 300,000 dwelling units were wiped out, and 750,000 persons were made homeless. At least 60,000 persons were killed.

## Characteristics of Fire Storms

The great fires which gave rise to the term "fire storms" occurred in Hamburg, Kassel, Darmstadt, Dresden, and perhaps to some extent in other cities which had airset fires over large areas. The common characteristics of these fires are described below:

*a.* Heavily built up city areas were blanketed with a high density of incendiary and high-explosive bombs. The density of the incendiary bomb fall was so great that individual efforts in combating incipient fires were fruitless. It was estimated that within 20 minutes after the first wave had attacked Hamburg, two out of three structural units within a 4.5 square mile area were afire as a result of one or more incendiary bomb strikes. In Darmstadt (population 109,000) in a slightly longer period, two out of every three structures were burning in upper stories as a result of incendiary bomb strikes. This rapid ignition of a large area distinguishes a fire storm from peacetime conflagrations of the past, which usually developed over a period of hours from one small start.

*b.* In the absence of a strong ground wind the interacting fire winds, set up by many individual fires augmented by the effects of heat of radiation over intervening spaces, merged the aggregate blazes into one inferno with its own pillar or column (thermal) of burning gases, which rose almost vertically. Over Hamburg this pillar was more than 2½ miles high and about 1½ miles in diameter. The term "fire storm" was used to describe these fires because in some places the pillar (or thermal) struck a stratum of cold air condensing moisture on motes of soot and debris which fell in large black raindrops directly to leeward of the fire area.

*c.* The rapid burning of great amounts of combustible materials was accompanied by a corresponding consumption of air, causing an influx of new air at the base of the pillar. This onrush of air, or fire wind, reached gale-like proportions as it headed toward the fire center. One and a half miles from the fire area of Hamburg this draft increased the wind from 11 miles per hour to 33 miles per hour. At the edge of the area, where velocities must have been appreciably greater, trees 3 feet in diameter were uprooted. The phenomenon of fire wind can be observed on a small scale in the simple burning of a bonfire where some of the gases are given off faster than they are burned, causing a pillar of unburned and burning gas and an onrush of air along the ground to supply the oxygen for combustion.

In these great German fires temperatures were raised to the ignition point of all combustibles and complete burn-out followed. The fires burned for nearly 48 hours before the areas cooled off sufficiently for them to be approached. No traces of unburned combustible building materials or plant life could then be found. Only the brick building walls and a few large charred trees remained.



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## Fire Spread

In the absence of fire-storm conditions fires in German cities seldom spread beyond physical fire barriers such as fire walls and open spaces. It was indicated that under light-to-average weight attacks where fire conditions were normal, a 10-foot space between two brick buildings had about a 50-percent chance of preventing fire spread, and that a parapeted fire wall between them had about a 90-percent chance.

However, fire barriers were ineffective in the great fires where fire storms developed. In these attacks fire spread was characterized by (1) high-explosive bombs stripping off roof tiles, breaking windows, and exposing the contents of buildings, (2) flying brands carried by convection currents spreading fire from building to building. All this spread was toward the fire center. If not hit by bombs buildings were ignited by flying brands.

Radiated heat undoubtedly contributed to fire spread, but its effect was difficult to distinguish from that spread by direct flames and brands. In the great fire storms which caused complete damage, fire spread was believed to have caused the damage to about 30 percent of the buildings.

## Fire Defense Operations

Defense against fire resulting from air attack was threefold: (1) Fire fighting by the residents of dwellings and apartments, (2) fire fighting by organized fireguards, factory employee groups, and civilian agencies, and (3) fire fighting by the professional fire-fighting services.

Householders and fireguards developed considerable ability in handling small incendiary bombs. For instance, in Hamburg in an attack in March 1941, 1,318 4-pound incendiary bombs dropped on houses were counted. Of these, 34 percent were disposed of by fireguards. However, in mixed attacks fireguards generally did not emerge from shelters until they believed the attack was over. By that time fires started by the attacks had passed the incipient stage where they could be controlled by individual action.

European fire departments were well equipped and adequate for peace-time needs. Solid building construction, strict height limitations, and the lack of exterior combustible materials had made it possible to limit fires to small areas and had obviated the need of high-powered fire equipment common to this country. It was recognized during the war that such heavy apparatus would have been of great value particularly for taking water from static supplies at great distances.

The underground water-supply system had been built primarily for domestic use. As the per capita consumption averaged about 35 gallons per day, as compared to 200–300 gallons per day common in many cities of this country, the need for large mains and pumping capacities was considerably lower. As a consequence, the typical European metropolitan water distribution system consisted principally of 4-, 5-, and 7-inch mains, generally well gridded, and supplied by feeder mains up to 30 inches in diameter.

It was German practice to take water supplies from rivers and canals when accessible. In addition, numerous concrete static water tanks varying in capacity from 100,000 to 1,000,000 gallons were installed in convenient locations to augment the primary supply.

Early in the war it was realized that water supplies would be damaged by ruptures of mains and would be inadequate to fight fires caused by bombing attacks. Additional static supplies consisting of sunken or semi-sunken containers of concrete ranging from 50,000- to 250,000-gallon capacity were constructed in most cities and towns. On some streets surface tanks of concrete were added which had, however, no mechanical means of refilling and were often pumped dry before fires were extinguished.

Despite methodical and efficient preparation, a record of the great fires which occurred in Germany reveals how ineffective fire-fighting forces were to control fires. The city of Hamburg is a case in point. The fire department there had a strength of 3,400 officers and men, 288 vehicles and 36 fire boats combating the great fires which occurred between July 24 and August 3, 1943. Within 20 minutes after the dropping of the first bomb a great mass fire was in progress, which reached its climax 2 or 3 hours later. The fire drew air toward it from all directions with such velocity firemen were unble to come within range with hose streams. Much of the fire equipment was lost, water supplies were disrupted, and being without radio communication the fire department found it exceedingly difficult to assign what units they had with any degree of efficiency. Those in command had difficulty in obtaining reliable information at their control point as men who were placed at observation posts could not see because of the dense clouds of smoke.

*Mutual aid.*—Forces from out of the city were organized at the outskirts, where they were met by couriers and were informed of the situation and their assignment. Emergency maps were provided, showing the sector to which they had been assigned, together with the nearest available water supply. This plan proved of much value in providing equal distribution and prompt operation of the units arriving at the fire. The chief officers confined their operations to buildings on the edge of the fire which offered the best opportunity of success, taking into consideration the values involved They dispatched the more inexperienced volunteers to extinguish fire brands on roofs and other places by use of hand extinguishers.

*Demolitions.*—The Germans seriously considered demolishing buildings with explosives to create firebreaks. However, the speed with which the fire traveled and the frequent change in direction due to the unusual air currents and radiated heat made the selection of suitable locations impossible. The German fire departments are now firmly convinced that such a practice in time of mass fires of wartime proportions is not sound and causes needless destruction.

*Results.*—The firemen devoted most of their initial efforts to saving lives and later fought fires at selected points. After the fires had diminished to an extent where they were no longer dangerous the areas were blocked off and either left to burn themselves out or were extinguished by firemen. The fire department of Hamburg reported extinguishing fires in 2,427 buildings and preventing the extension of fire to 635 buildings all on the fringe of the fire areas.

### Casualties

The principal loss of life in German cities occurred in the fire-storm cities. A variety of figures has been quoted. From somewhat incomplete data an estimate of 500,000 deaths was established by the U. S. Strategic Bombing Survey. This figure did not include the great loss of life reported in Dresden. Survey teams did not get into Dresden, but fire department officials in other localities have stated that the loss of life there was greater than that suffered in Hamburg.

## FIRE WARFARE ON JAPANESE CITIES

Warfare by fire from the sky reached its climax in the campaign against the Japanese homeland. The Twentieth Air Force dropped 93,000 tons of incendiary bombs and 650 tons of high-explosive and fragmentation bombs in 79 major missions directed against 64 cities. About 175 square miles of nearly 100-percent damage resulted (photo 1).

In contrast to the practice of bombing German cities with a 50–50 load of incendiary and high-explosive bombs, less than 1 percent of the total load dropped on Japan's urban areas consisted of high-explosive bombs. It was reasoned that large-scale incendiary attacks would create such havoc and confusion that the civilian and professional fire fighters would be overwhelmed, the water supply exhausted, and such intense heat created that fires would progress virtually unchecked until they reached the open spaces.

### The Pattern of Japanese Cities

Japanese cities were densely built up regardless of their size, and even small towns had densely built up cores. Tokyo, to take the most outstanding case, had 22.5 square miles of residential area with a building density of 46 percent. Ten cities were measured in detail by photo interpretation for building density and later spot-checked for accuracy. In these cities building density in residential areas varied from 11 to 49 percent, manufacturing areas from 33.6 to 45 percent, and mixed residential and manufacturing areas from 28 to 50 percent.

The typical Japanese dwelling was a flimsy one- or two-story frame building with a tile roof. Floors were ½-inch boards covered by rice straw "tatami" mats. Walls were made of bamboo laths thickly coated on both sides with a natural cement mud, and exterior sides were weather-protected by a wide unpainted lapboard.

There was at least 3 feet of space between dwellings whenever conditions permitted. Often, however, eaves had so much overhang that they touched those of the next building. In the crowded centers of every city, buildings were touching without any fire wall or space between (photo 2).

Commercial structures were largely of two-story frame construction. In large cities substantial fire-resistive department stores were found which contained, however, a large variety of combustible merchandise. The few load-bearing brick wall buildings for commercial use were similar in construction to those in the United States. Exposure protection devices such as wire glass windows, shutters, outside water curtains, and fire doors were usually lacking. Noncombustible structures of corrugated iron or asbestos cement on light steel frames were similar to those of Western construction. They were found only in industrial plants and usually had highly combustible contents.

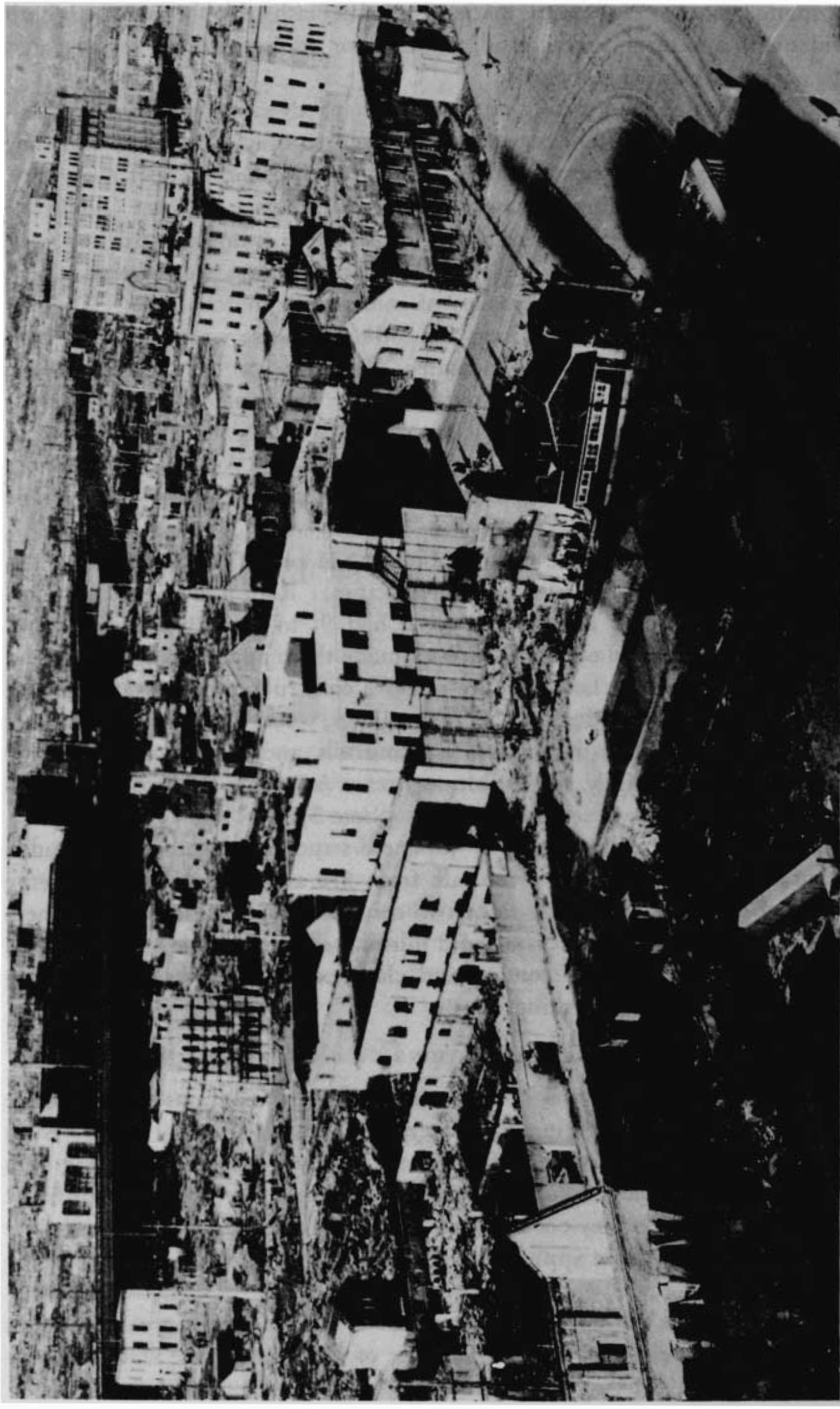
The modern earthquake-resistant building of extra-heavy reinforced concrete found in Japan was a massive structure. Roof and floors had minimum thickness of 6 inches, and some had 9- to 14-inch concrete roofs. Heavy haunches and outside buttresses made them appear extra strong and invulnerable. Here, however, fire-resistive construction stopped, for wood-lath and plaster partitions, suspended ceilings, wood-overlay floors with air spaces beneath, wood-trim stairways, handrails, and even doorknobs, made the interiors especially susceptible to fires. Adequate protection for outside wall openings was seldom provided (photo 3).

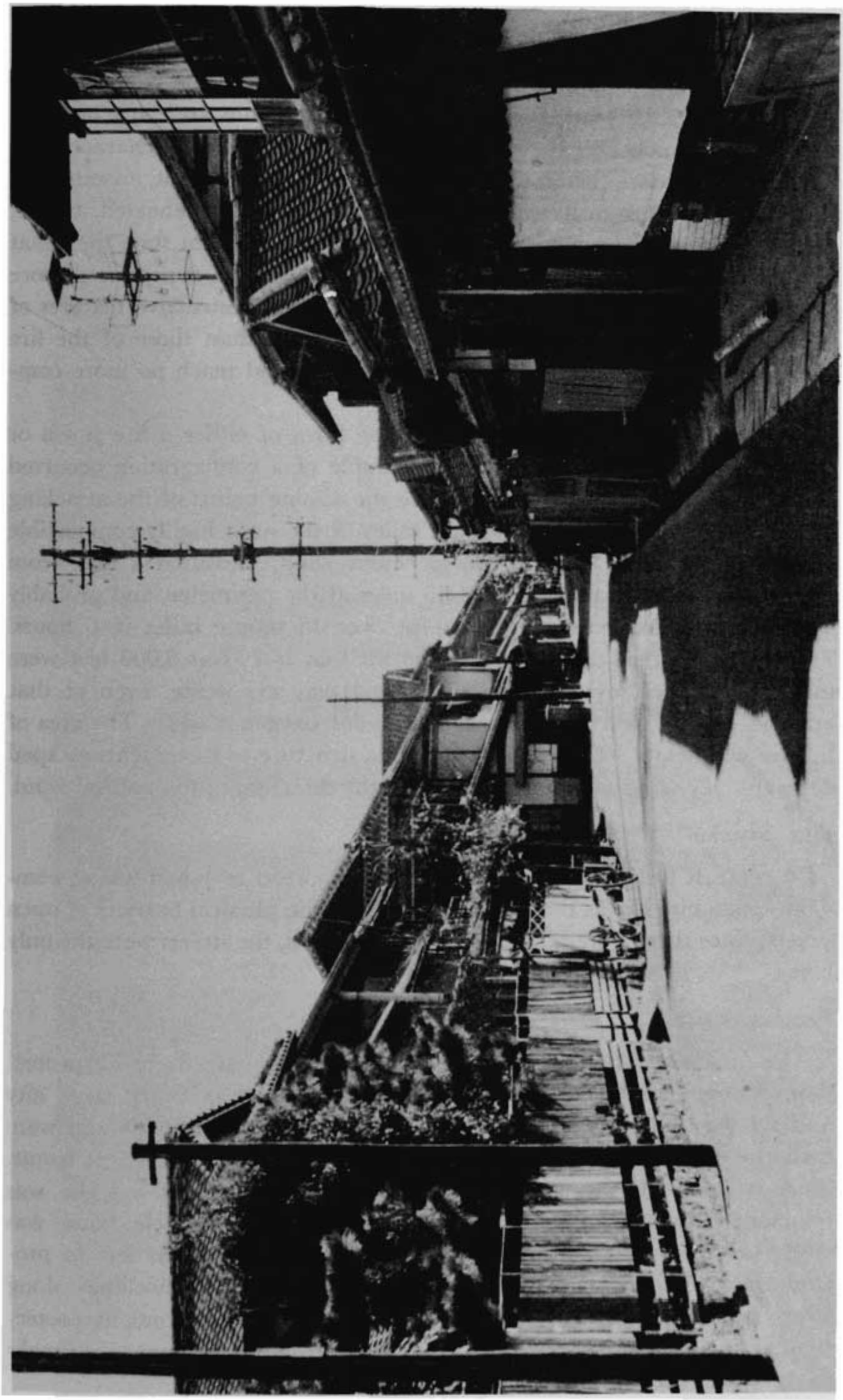
From this brief description of Japanese structures it can be concluded that only a few buildings were safe from fire and could effectively serve as area fire stops, especially since two concrete buildings seldom adjoined. Conditions were conducive to rapid burning of combustible structures and to fire spread by actual contact and close exposure rather than by long periods of radiant preheating.

### Characteristics of Conflagrations

In peacetime the term "conflagration" is often used loosely to describe fires in several buildings, in a manufacturing plant, or in a city block. Even though fire spread may occur from some buildings to other adjoining ones such fires are unlikely to spread outside the plant area or beyond the block or group in which they occur because of fire-wall barriers, streets, or other open spaces. A more appropriate term for that type of large fire would be "group fire."

In this report the term "conflagration" is used to signify great mass fires entirely out of control. In the presence of a strong surface wind a poten-





tial fire storm was transformed into a conflagration. The initial fires, in merging, spread considerably to leeward. The pillar, once it had been established, slanted appreciably to leeward; the higher the wind velocity, the more the pillar leaned over and the closer the hot and burning gases approached combustible materials on the ground. The chief characteristic of the conflagration, therefore, was the presence of a fire front, an extended wall of fire moving to leeward, preceded by a mass of preheated, turbid, burning vapors. The pillar was in a much more turbulent state than that of the fire storm, and, being usually closer to the ground, it produced more flame and heat, and less smoke. The progress and destructive features of the conflagration were consequently much greater than those of the fire storm, for the fire continued to spread until it could reach no more combustible material.

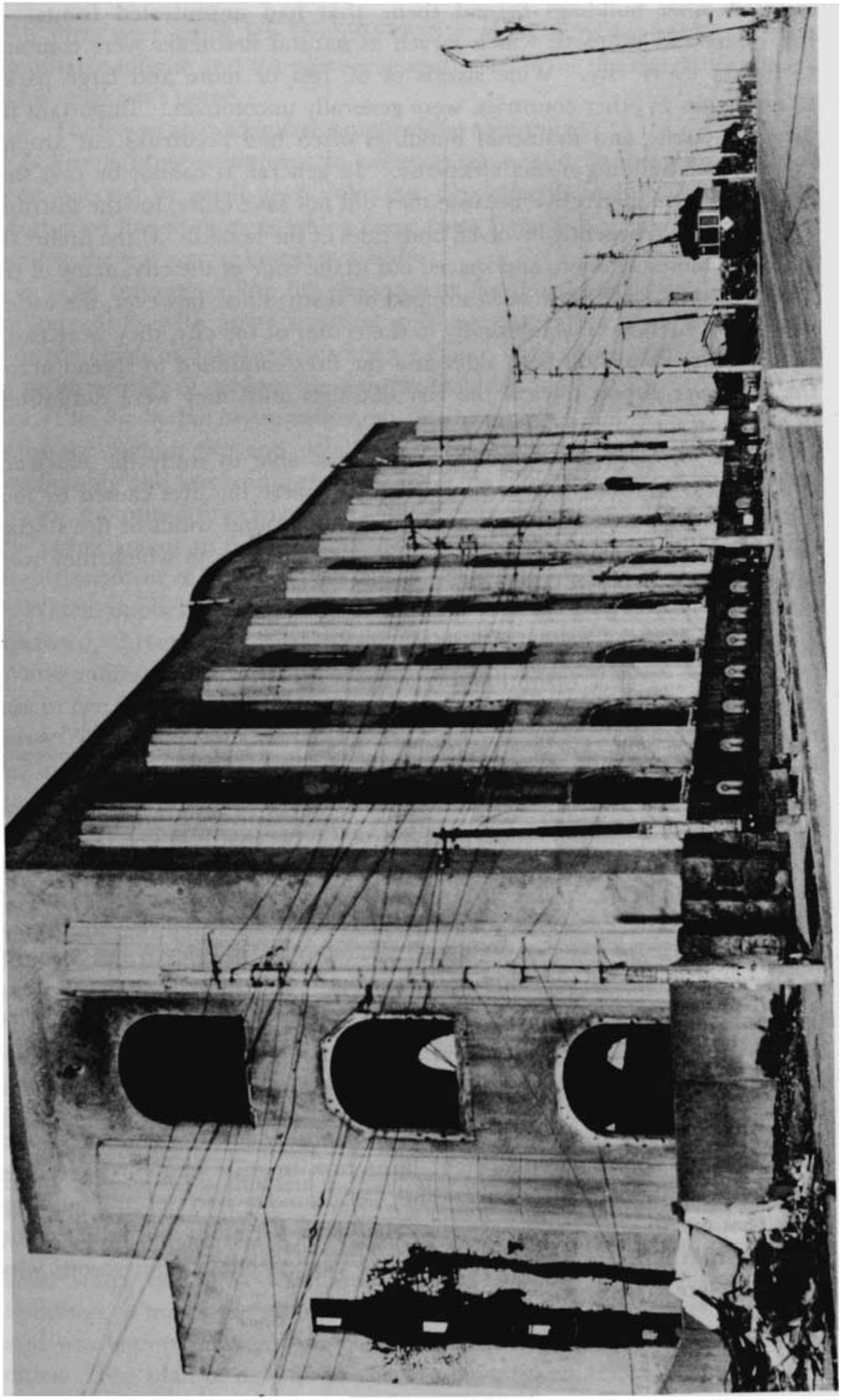
In Japan great fires sometimes took the form of either a fire storm or a conflagration. The most notable example of a conflagration occurred in Tokyo on March 9–10, 1945. Here the aiming points of the attacking force were chosen to cover 8 square miles of the most highly combustible portion of the city The 28-mile-per-hour wind, measured a mile from the fire, increased to an estimated 55 miles at the perimeter, and probably more within. An extended fire swept over 15 square miles in 6 hours. Pilots reported that the air was so violent that B–29's at 6,000 feet were turned completely over and that the heat was so intense, even at that altitude, that all men in the planes had to don oxygen masks. The area of the fire was nearly 100-percent burned; no structure or its contents escaped damage. The fire had spread largely in the direction of the natural wind.

### Fire Spread

In contrast to the German experience, fire spread in Japan was so common within city blocks that it stopped only at the physical barriers of open streets; since there were no brick walls or parapets, the streets were the only breaks.

### Firebreaks

The Japanese put their faith in entirely inadequate firebreak protec tion. Some man-made firebreaks were constructed in every large city and a few small ones. They ranged from 80 to 180 feet wide and were made by removing one or two layers of dwellings along the street fronts. Since a home owner was only partly reimbursed for his loss, he was reluctant to tear down his home ana, in some cases, where the house was costly or the owner politically influential, the dwelling was left to protrude into the firebreak itself. Many of the stores and dwellings along street fronts had imitation stone, metal-clad, or stucco fronts as protection against exposure fires; removing these structures to make firebreaks





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exposed other buildings behind them, that had unprotected fronts. A few rivers and railroads which served as natural firebreaks were common to almost every city. Wide streets of 60 feet or more and large parks, so numerous in other countries, were generally uncommon. Important individual public and industrial buildings often had firebreaks cut around them at the building owner's expense. In general, it cannot be said that firebreaks were ineffective because they did not save cities, for the distribution of bombs frequently involved both sides of the breaks. If the firebreaks had been more common, and spaced out to the edge of the city, many of the fires probably would have been stopped by them; since, however, the widest streets and firebreaks were usually in the center of the city, they were easily straddled by bombs on both sides and the fires continued to spread across the narrower streets toward the city outskirts until they were diminished or halted by the thinning out of buildings.

The U. S. Strategic Bombing Survey was able to study the efficiency of firebreaks in residential areas of Nagoya, where the fires caused by four major attacks were not complicated by strong ground winds or fire storms. Here firebreaks retained about 53 percent of the fires to which they were subjected. A detailed tabulation follows:

*Efficiency of firebreaks in residential areas*

[Distances in linear miles]

| Width | Length | Subjected to fire | Percent total | Fire stopped [1] | Percent stopped |
|---|---|---|---|---|---|
| 150 feet or over | 18.1 | 9.2 | 50.8 | 6.9 | 75.0 |
| 65 feet to 150 feet | 18.9 | 11.2 | 59.2 | 3.9 | 34.8 |
| Total | 37.0 | 20.4 | 55.1 | 10.8 | 52.9 |

[1] Fires were considered "stopped" where incendiary damage existed directly on one side of the firebreak only. This is, therefore, a measure of minimum efficiency because fires on both sides were often caused by bombs falling on both sides and not by fire spread.

It is interesting to note that the wider firebreaks were more than twice as effective as the narrower ones.

## Fire Defense Operations

The Japanese had seriously doubted our ability to attack in force, and they were poorly prepared to fight large fires in spite of their peacetime experience with conflagrations. The Government had set up building rules that eventually would have provided more fire stops and reduced the conflagration hazards, but these were not carried out. The reasons why the cities were so poorly prepared were:

*a.* Fires were much less frequent than in the United States, fire being a punishable offense and the party responsible liable for the fire damage done to his neighbor's home.

*b.* There was an inadequate supply of fire equipment.

*c.* Fire-fighting equipment in common use would, in a large part, have been rejected by small-town volunteer departments in the United States. Most good fire equipment which came from Germany or the United States prior to the war was no longer available.

*d.* The training of the fire-department personnel emphasized primarily military drills with goose stepping and saluting rather than fire fighting. The fire chiefs and many subordinate officials were police officers with little or no knowledge of modern fire-fighting techniques.

*e.* The Keibodan organization, an auxiliary police and fire unit set up to assist the regular fire and police departments, was also poorly trained in fire fighting and was equipped with only a few 250-gallon-per-minute, hand-drawn, motorized fire pumps. In many cases they would draw water from the public mains to fight isolated home fires, thereby depriving the public fire department of essential water.

Water supplies were generally weak and depended largely on electrically operated, direct pumping systems with little or no reservoir capacities. Water mains and fire hydrants were too few and too small for extensive use in fire fighting. Tokyo had a storage capacity of 8 gallons per person, while Akashi had 2 gallons per person. Only Nagoya seemed to have an adequate water supply, but even it was weak compared with the 200 to 300 gallons per person per day common in American cities.

The fire departments soon learned that it was hopeless to attack a fire where bombs were falling. They left those areas to get at the fringe of a fire, or where there was a good water supply. In these areas they had some success in preventing fire spread beyond wide streets and in controlling fires at the perimeters of fire storms and on the windward and parallel sides of conflagrations.

Individual fire fighters found that the small static water tanks of various sizes in streets of residential areas were useless except on the fire fringe. Hand buckets proved to be the most useful pieces of equipment for incipient fires.

The accounts of the attacks on Nagoya and Hachioji provide an interesting contrast. In both cities the preparations for fire fighting were superior to those existing in most other Japanese cities.

The city of Nagoya had an excellent fire department for Japan, a relatively good water system, a disciplined civilian population, many fire-resistive buildings, a multitude of parks, wide streets, canals, and other firebreaks, and was better prepared for incendiary attacks than most other Japanese cities. The plan of defense by the fire department stressed confining fires to previously prepared areas and attacking them along the perimeters. In practice this plan proved successful in combating four major attacks, which were not complicated by strong ground winds or fire storm. The water system remained generally in good working order although some sections of the city were sometimes without sufficient water pressure because of breaks in the mains. The fires were fought until they were finally controlled or until they were driven against natural or man-made obstacles. Streets were usually clear of debris, so that equipment had direct access to fires. Fire fighters avoided being trapped in the center of a fire. Control was obtained in windward sections by orthodox dousing with water. The leeward portions generally burned themselves out against parks, railroad beds, man-made firebreaks, wide roads, canals, fire-resistive structures and, especially in the second attack, previously burned out sections.

The attack on the city of Hachioji presented a different picture. The city had been warned of the impending attack by radio and leaflets, and as a result the city of Tokyo sent 50 of its largest pumper-type fire trucks and 300 professional firemen to assist the local fire department. As a result the greatest known concentration of men and equipment (55 trucks per square mile) ever gathered to fight a fire in any of the Japanese urban attacks was ready and waiting. Plans were made for the deployment of equipment and communications between companies, and the stage was set to wage a well-organized fight.

The water supply for the underground mains consisted of a filled 2,750,000-gallon reservoir on a hill. Three electrically driven pumps, each of 2,000-gallon capacity, took water from the river and were arranged to pump to the reservoir or directly into the system. The water main pipe sizes varied from 3 to 16 inches.

Within 15 minutes after the attack began, a cluster of bombs hit the electric switch station knocking out all electric power. The public water pumps failed so that the only supply for the underground system was the reservoir, which was exhausted in 1½ hours. Some 15 fire trucks were able to drive onto the sand beach of the river and draw water. The river was so low that no more trucks could get to the shallow beach pools. Relaying of the water was not attempted. A number of the trucks caught fire, hose was burned, and one truck had its motor knocked out by a direct hit by an incendiary bomb. The fire raged almost unimpeded, spreading across all the main streets and consuming 0.95 square mile of the 1.4-square-mile city proper.

### Casualties

It was estimated by the U. S. Strategic Bombing Survey that 168,000 persons died, 200,000 were seriously injured, and nearly 8,000,000 persons were made homeless by the major incendiary attacks on Japanese cities.

The great attack on Tokyo March 9–10, 1945, alone accounted for half of the total deaths. This attack caused more deaths than either of the atomic bomb attacks, and more than the great Hamburg, Germany, attack. Probably more persons lost their lives by fire at Tokyo in a 6-hour period than at any time in the history of man. The results were due principally to the element of surprise, dense population, highly built up combustible area, and ignition during a high wind.

## FIRE FROM THE ATOMIC BOMB ATTACKS ON HIROSHIMA AND NAGASAKI, JAPAN

The power of the atomic bomb to cause fire is illustrated in the story of what it did to the cities of Hiroshima and Nagasaki.

The first atomic bomb ever to be used against a target exploded over the city of Hiroshima at 8 :15 on the morning of August 6, 1945. The attack came 45 minutes after the all-clear had been sounded from a previous alert, and most of the people were either in flimsily constructed buildings or in the open (photo 4).

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

When the atomic bomb exploded (at 11: 02 a. m.) 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 undamaged 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 (photo 5).

The Hiroshima bomb exploded about 2,000 feet above ground and the Nagasaki bomb about 1,700 feet above ground. As estimated and described by scientists the bomb had changed into a fireball hotter than the center of the sun (70,000,000° C.) during the detonation, which was over in less than a second.

Energy was released by the bomb in three forms, and all the effects of the bomb can be referred directly to these three kinds of energy:

(1) Heat, probably exceeding 3,500° C. at ground zero (ground point directly beneath explosion) for about 3 seconds.

(2) Blast or pressure (as from a high-explosive bomb).

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

The hazards of blast and fire were known to us before in the action of high-explosive and incendiary bombs, but the radiation hazard is new. This study will be limited to a discussion of the fire effects of the atomic bomb with such reference to blast effects as is necessary to complete the picture of damage caused by the bomb.

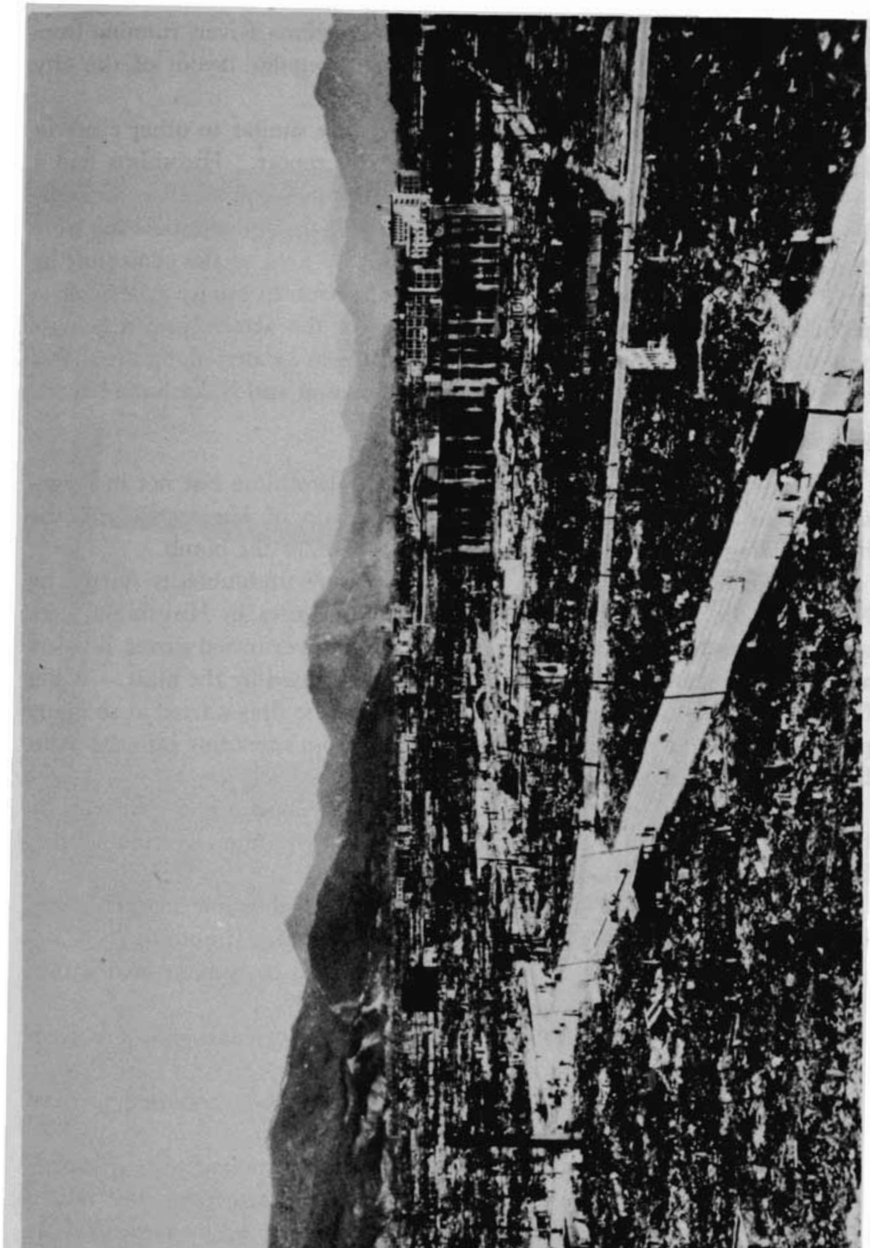
On the basis of the known destructiveness of high-explosive and incendiary bombs it is interesting to estimate the number of such bombs that would cause equivalent damage to the atomic bombs dropped on Hiroshima and Nagasaki. It would take 1,300 tons of bombs (¼ high explosives and ¾ incendiaries) at Hiroshima and 600 tons (¾ high explosives and ¼ incendiary) on Nagasaki to produce the same amount of damage.

It should be kept in mind that the damage at Nagasaki does not represent the full potential effectiveness of the atomic bomb used there, which was more powerful than the bomb dropped on Hiroshima. 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 probably have been several times as large. An equivalent bomb load which would correspond to the estimated destructive power of the Nagasaki bomb, if dropped on a target with flat terrain, would approximate 2,200 tons of high explosives and incendiaries for physical damage, plus 500 tons of fragmentation bombs for casualties.

## The Pattern of the Cities of Hiroshima and Nagasaki

The city of Hiroshima was located on the broad fan-shaped delta of the Ota River, whose seven mouths divided the city into six islands which projected fingerlike into Hiroshima Bay of the Inland Sea. These mouths of the river furnished excellent firebreaks in a city that was otherwise flat and only slightly above sea level. 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 of the bomb.

Nagasaki was located on the best natural harbor of western Kyushu, a spacious inlet in the mountainous coast. The city was 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, formed the two main valleys in which the city was built: The Urakami River, in which area the atomic bomb fell, running into the harbor



from a north-northwest direction, and the Nakashima River, running from the northeast. This mountain spur and the irregular layout of the city effectively reduced the area of destruction.

The physical characteristics of both cities were similar to other cities in Japan described in the preceding section of this report. Hiroshima had a built-up area of some 13 square miles with a population of approximately 245,000 at the time of the attack. About three-fifths of the population were contained in 4 square miles of a densely built up area at the center of the city. Nagasaki, with a metropolitan area of about 25 square miles, and a probable population of 230,000 at the time of the attack, had a heavily built up area of less than 4 square miles, which was located along the shores of its harbor and up the two valleys of the Urakami and Nakashima Rivers.

## Fires Caused by the Atomic Bomb

The phenomenon of fire storm occurred in Hiroshima but not in Nagasaki. This was due probably to the flat terrain of Hiroshima and the high building density below the point of explosion of the bomb.

Although many fires close to ground zero were undoubtedly started by heat from the flash (primary fire), most of the fires in Hiroshima were secondary, resulting from electrical short circuits, overturned stoves, braziers and lamps, broken gas lines, and other damage caused by the blast. While firebreaks in general did not prove effective because fires started at so many places, at the same time they did prevent fires from spreading into the main business and residential areas of Nagasaki.

Evidence relative to ignition of combustible structures and materials by heat directly radiated by the atomic bomb and by other ignition sources in Hiroshima indicated that—

(1) The primary fire hazard was present in combustible materials and in fire-resistive buildings with unshielded wall openings (photo 6);

(2) Black cotton black-out curtains were ignited by radiant heat within 3,200 feet of ground zero;

(3) Thin rice paper, cedarbark roofs, thatched roofs, and tops of wooden poles were afire immediately after the explosion;

(4) Dark clothing was scorched, and, in some cases, reported to have burst into flame from flash heat;

(5) A large proportion of over 1,000 persons questioned were in agreement that a great majority of the original fires were started by debris falling on kitchen charcoal fires, by industrial process fires, or by electric short circuits.

The fire storm in Hiroshima began to develop soon after the start of the initial fires and included both wind and rain. Although the velocity of the wind on the morning of the attack was not more than 5 miles per hour, the fire wind, which blew continuously toward the burning area, reached

a maximum velocity of 30 to 40 miles per hour 2 to 3 hours after the explosion. As the fire wind increased in intensity, fires merged to include virtually all the built-up center of the city. However, practically all fire spread beyond 6,000 feet from ground zero had ceased 2 hours after the attack. A large portion of the burned-over area resulted from the spreading and merging of the original fires. Beyond 5,000 feet from ground zero, building density influenced the extent of fire spread. In round numbers, 68,000 out of Hiroshima's 75,000 buildings were destroyed or seriously damaged.

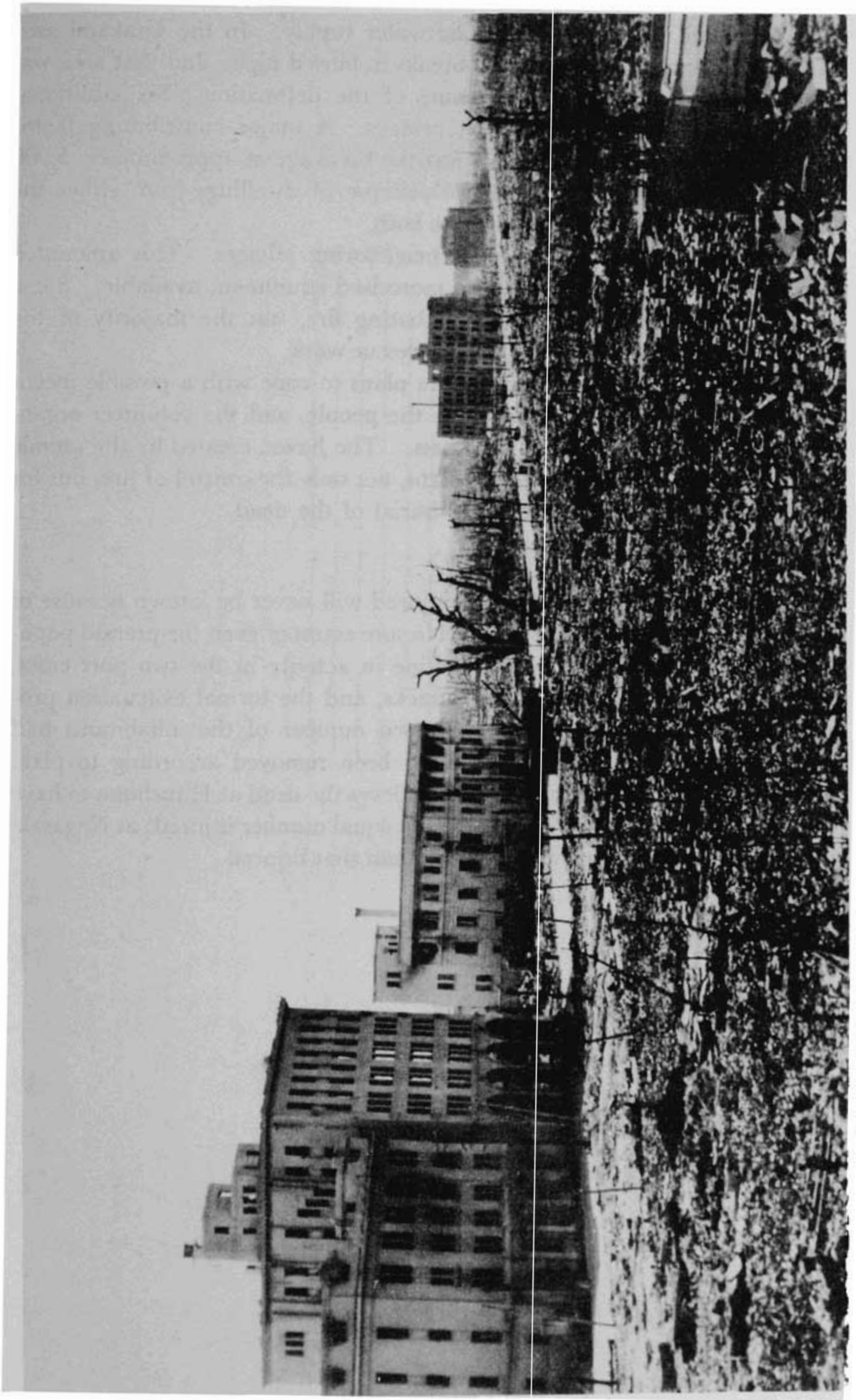
The fires in Nagasaki were exceedingly difficult to trace. The building density in these areas—especially beyond 2,000 feet of ground zero—was erratic, dwellings being clustered in valleys and here and there on terraces and hillsides. The built-up area, 6,000 to 8,000 feet south and southeast of ground zero, was much more uniform. Interrogation disclosed that irrespective of the direction of the light ground wind, fire spread south and southeastward, swept up hillsides, and burned buildings already damaged or collapsed by the blast. This phenomenon occurred 7,000 to 8,000 feet from ground zero and within 2 to 3 hours after the detonation. At 8,000 to 11,000 feet south and southeast of ground zero, fires were started at the time of the blast in some of the buildings and, as these buildings burned, spread to others in the vicinity. In all, blast and fire destroyed or seriously damaged 20,000 out of Nagasaki's 52,000 buildings.

## Fire Defense Operations

Fire fighting in Hiroshima was effective only at the outer perimeter of the fire-storm area and in 4 of the 58 fire-resistive buildings which were fire-damaged. The public fire department and rescue units played a minor role in the extinguishment of the fires as 80 percent of the firemen on duty had been killed or critically injured, 60 percent of the public fire stations totally damaged, and 68 percent of the fire trucks destroyed. As a result only 16 pieces of fire equipment were available.

Most of the fire had burned itself out or had been extinguished by early evening of the day of the attack. A combination of fire wind, fire fighting, streets acting as fire breaks, and low building density stopped the fire at the perimeter. Hand fire equipment used in saving many dwellings on the fire fringe proved to be the most effective fire-fighting equipment. Exposure distance between buildings on the fringe had a direct bearing on the extent of fire spread.

Direct damage to the fire department in the Nagasaki attack was much less than at Hiroshima. The paid fire department lost only two fire stations and one truck. The auxiliary police and fire units lost four fire stations and four pieces of equipment. Casualties were minor as compared to the Hiroshima loss. However, the effect of fire fighting was negligible mainly



because of the failure of the public water supply. In the Urakami area toward the north, there were five breaks in buried pipes, and that area was totally without water from the time of the detonation. Six additional breaks occurred, four of them at bridges. A major contributing factor to the failure of the water supply was the breakage of approximately 5,000 house service pipes, because of the collapse of dwellings from either the blast or the destruction by fire, or from both.

Assistance was summoned from neighboring villages. This amounted to manpower only, as there was no motorized equipment available. Some of the rescue workers aided in combating fire, but the majority of the people called in devoted their efforts to rescue work.

The prefecture had made elaborate plans to cope with a possible incendiary attack. Instruction was given the people, and the volunteer organization was mobilized and in readiness. The havoc created by the atomic bomb completely disorganized all plans, not only for control of fire, but for rescue work, care of wounded, and burial of the dead.

## Casualties

The exact number of dead and injured will never be known because of the confusion after the explosions. 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 attacks, 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. The U. S. Strategic Bombing 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.

## SECTION II

# Principal Factors Involved in the Fire Susceptibility of American Cities

THE residential sections, much of the commercial and business sections, and the older industrial sections comprising the major portions of American cities are made up predominantly of load-bearing, masonry-wall, and wood-frame buildings. They are highly susceptible to fire and blast, and the disasters that occurred in the cities of Germany and Japan could happen here.

No two cities, whether in this country or in other countries, are exactly alike. But differences in layout, building density, combustibility, terrain, and other factors can be appraised individually. When this is done comparisons are possible. For instance, the most striking difference between American and Japanese cities is in residential districts. However, Japanese cities contained many brick and wood-frame buildings of Western or similar design and of good workmanship. It was the opinion of the engineers of the U. S. Strategic Bombing Survey, with their professional familiarity with American buildings, that these Japanese buildings reacted much as typical American buildings would have done. These buildings proved to be exceedingly vulnerable to the atomic bomb. The following table details the property damage caused by blast and fire in the atom-bombed cities. Because of the absence of a fire storm, the blast effects were more striking in Nagasaki than in Hiroshima.

| Destruction or severe damage | At Hiroshima | At Nagasaki |
|---|---|---|
| Brick buildings: | | |
| 1 story | 6.0 sq. miles | 8.1 sq. miles. |
| Multistory | 3.6 sq. miles | |
| Concrete buildings (reinforced): | | |
| Poor construction | Up to ½ mile from ground zero. | Up to 1 mile from ground zero. |
| Heavy construction | "Few hundred feet" from ground zero. | "Few hundred feet" from ground zero. |
| Steel frame buildings: | | |
| Light, 1 story | 3.4 sq. miles | 3.3 sq. miles. |
| Heavy construction | | 1.8 sq. miles. |
| Wood buildings: | | |
| Dwellings | 6.0 sq. miles | 7.5 sq. miles. |
| Industrial (poor construction) | 8.5 sq. miles | 9.9 sq. miles. |

The foregoing figures indicate what would happen to typical wood and brick structures in American cities under attack by the atomic bomb. Modern reinforced concrete 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 such blast-resistant and fire-resistant construction.

| City | Types of structures by exterior material (U. S. cities)[1] | | | | |
|---|---|---|---|---|---|
| | Total structures reported | Wood | Brick | Stucco | Other materials [1] |
| Chicago | 382,628 | 131,148 | 238,959 | 5,797 | 6,724 |
| Detroit | 267,677 | 165,488 | 94,533 | 1,923 | 5,933 |
| New York | 591,319 | 236,879 | 299,482 | 41,661 | 13,297 |
| San Francisco | 105,180 | 61,172 | 2,334 | 40,902 | 722 |
| Washington | 156,359 | 48,971 | 95,939 | 5,764 | 5,685 |

[1] Includes blast-resistant and fire-resistive buildings.

Source: Sixteenth Census of the United States (1940), vol. II.

It would be expected that the aiming point of an attack on an American city would be the central core of the city. If the attack were made with incendiary bombs the weight of the attack would be a major factor in the extent of damage; if by an atomic bomb the radius of initial damage would depend on the character of the bomb and the altitude of the explosion.

Our interest in the vulnerability of the various types of buildings to structural damage is only to provide a yardstick for measuring the value of these buildings as protection for vital processes and as human shelters. Japanese cities were very congested, and the population density was high.

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.

A comparison of population densities between five of America's largest cities and the atom-bombed cities of Japan may prove surprising.

*Population densities (U. S. cities—1940 census)*

| City | Population | Square miles | Density population per square mile |
|---|---|---|---|
| Chicago | 3, 396, 808 | 206. 7 | 16, 500 |
| Detroit | 1, 623, 452 | 137. 9 | 11, 750 |
| New York | 7, 492, 000 | 322. 8 | 23, 200 |
| San Francisco | 634, 536 | 44. 6 | 14, 250 |
| Washington | 663, 091 | 61. 4 | 11, 000 |
| Hiroshima (prewar) | 340, 000 | 26. 5 | 12, 750 |
| Nagasaki (prewar) | 250, 000 | 35. 0 | 7, 000 |

The foregoing figures are, of course, averages for people within the limits of a city and do not give a true picture of the concentrations of people within certain portions of those city limits. The following data give a better comparison of New York with Hiroshima and Nagasaki. The casualty rates at Hiroshima and Nagasaki applied to the massed inhabitants of Manhattan, Brooklyn, and the Bronx would yield a grim conclusion.

| City | Population | Square miles | Density population per square mile |
|---|---|---|---|
| New York: | | | |
| Bronx | 1, 493, 700 | 41. 4 | 34, 000 |
| Brooklyn | 2, 792, 600 | 80. 9 | 34, 200 |
| Manhattan: | | | |
| (Day) | 3, 200, 000 | 22. 2 | 145, 000 |
| (Night) | 1, 689, 000 | 22. 2 | 76, 000 |
| Queens | 1, 340, 500 | 121. 1 | 11, 000 |
| Staten Island | 176, 200 | 57. 2 | 3, 000 |
| Hiroshima, center of city (as of Aug. 1, 1945) | 140, 000 | 4. 0 | 35, 000 |
| Nagasaki, built-up area (as of Aug. 1, 1945) | 220, 000 | 3. 4 | 65, 500 |

## FACTORS HAVING THE GREATEST INFLUENCE ON FIRE INITIATON AND FIRE SPREAD

No matter what kind of weapons were used, initiation and spread of fire would be dependent on the fire susceptibility of the target city. Practically all the factors or characteristics of an urban area have some influence on fire susceptibility. The factors that appear to be most important in influencing extent and degree of fire will be discussed in the following pages.

1. Building Density

One of the most important factors influencing initiation and spread of fire in any city is its building density—the ratio of roof area to ground area. The more densely it is built up, the greater the number of individual fires; the less open space in which to fight fires, the more likelihood of contiguous or closely exposing buildings. We have found in the descriptions of great fires which developed the phenomenon of a fire storm in Germany that they all occurred in areas of high building density. The crowded building conditions of Japanese cities made them acutely vulnerable to mass fires. The building density of the fire-storm area of Hamburg was about 30 percent, and the fire-storm areas of other cities in Germany visited by this type of disaster were comparable. Tokyo, which provided the most outstanding example of a conflagration, had 22.5 square miles of residential area 46 percent built up. Hiroshima, which suffered a fire storm following the A-bomb attack, had a density of 27 to 42 percent in the 4-square-mile city center.

It is profitable to speculate on why there was no fire storm at Nagasaki. The wind conditions were favorable, and the heat radiation of the bomb was more intense than that of the bomb dropped on Hiroshima. While most of the initial fires in Hiroshima were started by secondary sources (kitchen charcoal fires, electric short circuits, industrial process fires, etc.) both Japanese and American fire experts agreed that more fires were caused directly rather than indirectly in Nagasaki in a ratio of 60 to 40. As fire fighting was ineffective in both cities it is reasonable to conclude that a relatively low building density as well as the terrain played a major role in preventing the development of a fire storm or a conflagration in Nagasaki.

Several studies were made of the influence of building density on damage in zones of Japanese cities. In one, the tendency of fire to spread from bomb-ignited areas through different degrees of building density was determined by measuring the areas burned and unburned in three residential zones of different degrees of building density. In these areas, 16 percent of the 5- to 20-percent built-up zone, 65 percent of the 20- to 40-percent built-up zone, and 82 percent of the 40- to 50-percent built-up zone were damaged, indicating strongly the relative fire vulnerability of different degree of building density.

In making an over-all comparison of cities in this country with those of Germany similarities as well as differences are noted. For example, the residential areas of American cities, away from the city center, run more to detached dwellings and a lower density than residential areas in

Germany. This is not true, however, of larger and older cities such as New York, Philadelphia, or Baltimore, where dwelling units over vast areas are built directly adjacent to each other and contain many "backyard" combustible structures. However, a close comparison exists between built-up commercial areas in Germany and the United States.

It is instructive to consider the growth of a typical block in the heart of an occidental city. Usually it begins by being chiefly residential. As the town grows, houses are converted into shops. Vacant spaces between buildings are filled in. Some buildings are wholly rebuilt. The backyards are taken up by storage buildings and small factories. Thus, not only are high fire-risk occupancies introduced but more of the ground is covered by buildings, increasing the building density. Greater amounts of combustible materials contained in the commercial and other occupancies facilitate the growth of uncontrollable fires, and the near exposure of the buildings increases the risk of fire spread.

A later stage is reached in the larger cities when site values become very high. The blocks tend to come into the ownership of a few concerns who erect large department stores, hotels, factories, office buildings, etc. While the building density is further increased, the fire risk now tends to become somewhat less because of fire-resisting construction, better departmentation, and better protective features. A final stage is occasionally reached when one large building occupies an entire block.

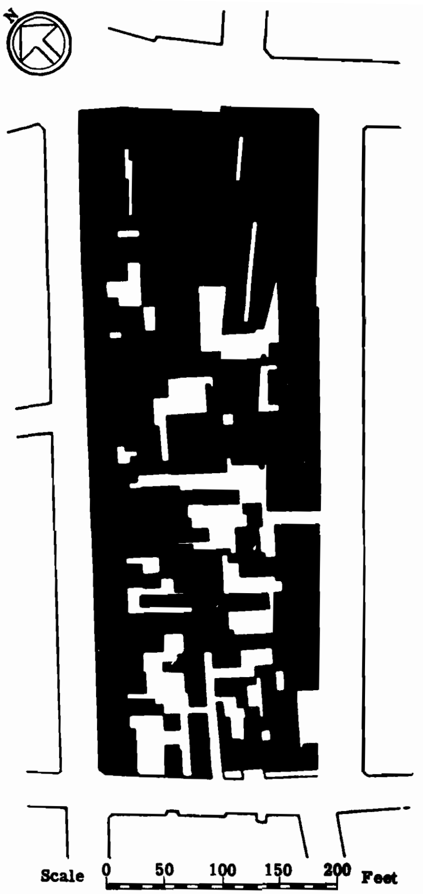
A typical high fire-risk block, chiefly mercantile, in a medium-sized city is shown in the illustrations on the following page. In this block the fire susceptibility is great because of the bulk and combustibility of contents stored in the buildings as well as the high building density and the possibility of fire spread by exposure.

A knowledge of the building density of American cities is fundamental to adequate planning for civil defense. The procedure suggested consisted originally of resolving the city area into subareas of fairly homogeneous building density. The limits of these areas were determined by areas of different building density and wide firebreaks. (See Firebreaks, p. 37.) While physical measurement would give the greatest accuracy it would be possible after a little practice to estimate density, block by block, from detailed city maps. After the limits of the zone were determined, the calculation of building density of that zone would be made according to the formula:

$$\frac{\text{Total ground area of buildings}}{\text{Total area of zone}} = \text{Building density}$$

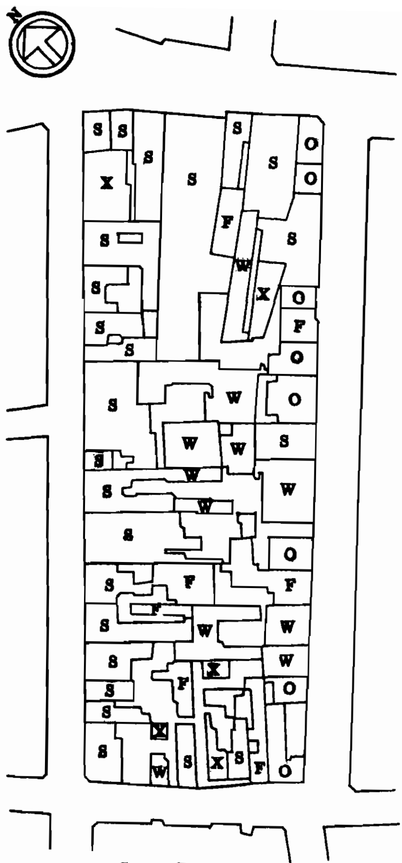
(The area of the zone would include streets, open spaces, etc.)

While no hard and fast conclusions can be drawn, it is probable that great mass fires of fire-storm and conflagration proportions can be expected only in areas of over 20-percent building density.




| | |
|---|---|
| AREA | 2.6 acres |
| BUILDING DENSITY OF BLOCK | 72% |
| BUILDING DENSITY INCLUDING STREETS | 65% |

Fig. 1. Analysis of a building block: the extent of the ground covered with building.




S = Shop
W = Warehouse
F = Factory
O = Offices
X = Others

Fig. 2. Analysis of a building block: the occupancies and properties.

## 2. Combustibility of Structures

Another factor of primary importance in the propagation of fire is the combustibility of structures. Building construction for the purposes of this study can be resolved into three major classifications in the order of their susceptibility to fire. These classifications are:

1. All frame construction.
2. Masonry—combustible.

(Buildings with masonry walls but with combustible material in their principal structural members, such as roofs and floors.)

3. Fire resistive.

(Buildings constructed of materials that will not support combustion and that will withstand all but the most intense fire without serious structural damage. Typical examples are all reinforced concrete structures, concrete and masonry structures supported by protected steel frame, and stressed-skin type, reinforced concrete structures.)

Noncombustible buildings constructed of materials which will not support combustion but which are vulnerable to damage by intense heat, such as unprotected steel frame structures with noncombustible coverings, are not included in these classifications since they are found in appreciable numbers only in manufacturing installations, and their influence on an over-all assessment of a city area would not be significant.

The typical dwelling and mercantile units in Germany came under classification 2; the dwellings and the majority of the commercial units of Japan came under classification 1. It must be recognized that the most significant difference in these classifications from a fire spread standpoint was the greater hazard of continuing fire in classification 1 because of exposure fires. Except in conditions of fire storm and conflagration, it was found that fire would be retained in most cases within the masonry fire walls of buildings of classification 2 and would not spread to contiguous and closely exposed buildings.

In this country lumber has been plentiful, and originally most of our buildings were built of wood. The use of wood shingles was widespread, and such roofs still exist to plague local firefighters and provide a great potential conflagration hazard. Huge highly conbustible structures have been built, and reliance has been placed on automatic devices such as sprinklers and high-powered fire departments to keep them from burning. Extremely tall buildings have also complicated the fire-control problem.

There were few, if any, wood-frame structures in the typical German city. Outside building walls of brick were of much heavier construction than those customary in the United States. In addition, all inside room and stair-well partitions were of brick, and no partitions of wood lath and plaster on wood were seen. • There were virtually no wooden porches, fences, garages, sheds, and other wooden structures in German cities as are very commonly found in the United States. First floors over basements of more recent construction in Germany were of concrete or arched brick with steel beams, and many known as "massive construction" had concrete stairs and floors above the first floor. In most cities, tile roofs over wood frames were used almost exclusively, even on buildings which were otherwise of fire-resistive construction. In Hamburg, most of the buildings had flat roofs which were on wooden joists, except in buildings of fire-resistive construction. The roofs of most German buildings were vulnerable to incendiary bombs because of the combustible supports. Modern business and industrial buildings constructed as fire-resistive were lacking in many respects the accepted standards for that type of construction in the United States.

However, the conclusion is inescapable that the buildings in the cities of Germany were less susceptible to fire storms and conflagrations because of the combustibility of structures than cities of similar size in the United States.

The cities of Japan, on the other hand, because of building density and combustibility of structures were more susceptible to conflagration than those of this country. However, the planners of the Japanese campaign were surprised that the cities did not burn as readily as expected. Moisture content of the wood (discussed in another section) may have been a contributing factor, but the fire load (b. t. u. content) also was less in Japanese than in European and American buildings. Inasmuch as great fires such as fire storms involve conditions when all the fuel is burning it is well to emphasize that the bulk mass of combustible material is much greater in American dwellings and the roof protection is considerably less than in Japanese dwellings.

Referring to the table on page 30 listing types of structures in five large American cities it is observed that only a small percentage are built of fire-resistive and blast-resistant materials and those contain combustible contents which will burn. The following table shows the percentage of such buildings in these cities:

*Percentages of fire-resistive and combustible structures in five American cities*
[1940 census]

| City | Percentage of structures by construction (United States cities) | |
|---|---|---|
| | Fire-resistive construction | Combustible construction |
| Chicago | 1.7 | 98.3 |
| Detroit | 2.2 | 97.8 |
| New York | 2.3 | 97.7 |
| San Francisco | Less than 1 | 99+ |
| Washington | 3.6 | 96.4 |

The foregoing percentages are based on numbers of buildings only and do not take into consideration the size and heights of these buildings. As the larger and taller buildings are more often built of noncombustible and fire-resistive materials these percentages would increase materially on an area basis, but even then they would be low. The superior type buildings in a city tend to be clustered together in high value commercial districts and to some extent in manufacturing, storage, and residential areas (modern apartment houses). This condition tends to reduce to some extent the combustibility and hazard of commercial zones where building density is usually highest. The location of such fire-resistive buildings should be examined with care to consider the probability of their acting as firebreaks. Judgment should determine the value that can be assigned to the factor of combustibility of buildings in assessing the fire susceptibility of the various zones of building density in American cities.

3. FIREBREAKS

In assessing the susceptibility to fire of American cities, it is necessary to consider firebreaks, which may prevent the spread of fire. Open spaces such as streets, parks, and canals, and sometimes, if properly located, fire-resistive buildings will serve as firebreaks. If fire storm and conflagration were absent, continuous parapeted fire walls completely across a combustible area could not stop fire spread. From a study of immunity to fire spread at Hiroshima between frame buildings it is apparent that an exposure distance of 50 feet would minimize the hazard of fire spread from atomic bomb attack. The manner in which streets and other open spaces affect spread of fire depends on their width and the size, height, combustibility, and density of the surrounding buildings, as well as wind conditions. Because so many factors are involved in determining the effectiveness of firebreaks, it would be misleading to state that any fixed width would be completely effective. Furthermore, fire could be started on both sides of wide firebreaks by radiant heat and dislocation by blast in atomic bomb attacks or as a result of incendiary bombs straddling fire breaks. While the average street widths common in American cities would probably have no effect in limiting fire spread in a fire storm, they could in limited fires or at the fringe of mass fires act as firebreaks. A practical long-range program of arranging firebreaks by removal of slum areas would reduce building density and the danger of fire spread.

The individual value of firebreaks must be considered on a relative basis in determining boundaries of zones and in arriving at an over-all estimate of susceptibility to fire of the area being analyzed.

4. Size of Target Area

The extent of fire damage caused by enemy attack would depend not only on the size of the city area but on the size of zones within the city capable of supporting such phenomena as fire storms and conflragations. The size of these zones would be determined by such things as building density, probably effective firebreaks, and the adjacent areas of low building density. Such firebreaks would determine the exterior limits of the zones and would be expected to stop the spread of mass fire.

The size of the zone would influence the number of fires that could be started to produce mass fire effects. The fire-storm area of Hamburg was 4.5 square miles, Kassel 2.9 square miles, Darmstadt 1.5 square miles, and Hiroshima 4.4 square miles. The several small mass fires in Nagasaki which did not produce a fire storm were all under 1 square mile. The minimum size of the area capable of sustaining a fire storm is uncertain, but a study of the data suggests that it is unlikely to be less than 1 square mile.

## CONTRIBUTING FACTORS TO FIRE INITIATION AND FIRE SPREAD

Practically all the characteristics of an urban area have an influence in some way on susceptibility to fire. In individual fires any factor may be dominant; consequently the following list, which is not all-inclusive, must not be ignored in the study of a particular city. The order in which these factors are listed has no significance.

1. Continuity of Combustible Construction

It has already been noted that exterior wooden construction is a very important factor in fire spread. Sheds, private garages, small storage buildings, and outhouses of various kinds have been built usually of wood in American cities. Again, continuity of combustible construction is also provided by continuous cornices, porches, fences, awnings, wooden additions to masonry buildings, etc. It may be necessary in an emergency to remove much of this construction in highly built-up areas in American cities. In any case the hazard of its existence should be recognized when analyzing the zones of cities and estimating their susceptibility to fire.

2. Occupancy Combustibility

Most of the fires caused by bombing in World War II originated in the combustible contents of the buildings and not in the structure itself. These fires at first were small and easily controlled.

It is obvious that the susceptibility of contents to fire is not uniform in different occupancies. Urban areas are composed of fairly homogeneous zones generally containing predominantly one type of occupancy such as residential, mercantile, manufacturing. Mercantile groups, for example, have a higher fire susceptibility than residential groups, and they suffered more in fire attacks in World War II. Fires developed more quickly to fill whole buildings. The large bodies of heat thus created ignited adjacent buildings more readily than residential buildings.

After American cities have been divided into building density zones, the predominant occupancy characteristics of these zones should be studied in judging their relative fire susceptibility.

### 3. Size of Buildings

Size of buildings, including both ground area and height as they influence the size of the individual fire and the ability to fight the fire, must be considered for assessment purposes. Area and height limitations are the least standardized of all building code requirements in this country, regardless of the structural type or occupancy involved. It has been common practice to permit large open area combustible buildings where automatic sprinkler protection has been provided. This condition increases the hazard of many American commercial and manufacturing buildings in comparison with German buildings, which were smaller on the average. Sprinkler protection under war conditions would be of no value if water mains were broken by blast and shock or the water supply was in sufficient. In considering the size and height factors of buildings as contributing to area susceptibility, too much reliance must not be placed on sprinklers as agents of control even though in cases where primary or secondary water supply was adequate they would succeed in controlling many fires.

### 4. Topography

Hilly terrain would have an influence on the production of mass fires. Fire might spread more easily when cities are built on hills. On the contrary, effectiveness of the A-bomb was reduced by hills in the city of Nagasaki where a range of hills effectively prevented fire from spreading from one valley to another.

The height at which an A-bomb is exploded will determine how much effect hills will have. Unless the explosion occurs at a very considerable elevation, any sizable hills will provide important shielding from the heat effects of the bomb. The influence of this factor would depend on the individual layout of the city involved as well as the point of origin of the fires.

## WEATHER FACTORS

Weather conditions over which defenders would have no control would influence fire spread in case of attack. However, the attacker would be expected to take advantage of these natural factors if they could be predicted, and the defense should not only be aware of them but should exercise special alertness in unfavorable periods.

1. Humidity

In general, the average humidity for a 3-week period determines the moisture content of a structure and (to a lesser extent) its contents. An average relative humidity above 70 percent in winter and 75 percent in summer will produce an equilibrium moisture content greater than 15 percent and will appreciably increase the difficulty of initiating a vigorous fire. Even in this case, however, if a sufficient quantity of combustible material in the form of lightweight panels, or in any other form characterized by large surfaces per unit volume, is present so that a good fire can be started despite the effects of moisture content, the fire can overcome the retarding effect of moisture in heavier members and cause extensive destruction. It is, therefore, only in the initial stages of a fire that humidity during the preceding 3 weeks is important. If the attack is severe enough to overcome this obstacle to fire initiation, humidity will be of minor importance in retarding fire propagation and spread.

2. Rain and Snow

In the 8 hours immediately preceding an attack and in the period immediately following the attack precipitation is an important factor. A heavy rain during either of these periods will not noticeably alter the ease of ignition of protected materials inside a building, but it should hamper the spread of fire from one building to the next. The reason for this is obvious, when it is recalled that a primary tactic in halting the spread of fire is to wet down all surfaces exposed to direct radiation of heat from burning buildings. The outer walls of buildings, if soaked with moisture, will resist fire spread longer, and thus give time for organized fire defenses to act. Absence of paint on the outer walls of a building will promote the absorption of moisture during a rainstorm and should, therefore, prolong the fire resistance of such buildings over a longer period than would be expected with painted walls where surfaces may become completely dry within an hour or two.

Snow does not hamper the spread of fire to the same extent as rainfall because the side walls of buildings, which are the chief surfaces exposed to heat radiation, do not become water-soaked. Snow on the roof, if melted by a fire, tends to run off through channels without wetting down the walls to any great extent. Serious fires have spread in peacetime in American cities while the buildings and ground were covered with snow to the depth of several inches.

### 3. Wind

It may be said that wind is the greatest potentially favorable weather factor in promoting a conflagration. With all other factors of fire susceptibility at a maximum it is possible that fires of moderate proportions could be controlled by determined defensive measures provided wind velocity is no greater than 15 miles an hour. As the wind velocity rises from 15 to 30 miles an hour, the rate of fire propagation from building to building increases enormously, and at the latter figure even a relatively minor blaze, involving a group of but two or three dwellings, may constitute a serious threat to the whole of the downwind area. An analysis of peacetime records of the most destructive conflagrations in the United States and Canada reveals that in nearly 25 percent of them high wind was the chief contributing factor, and in 58 percent of them it was one of the more important factors. It is likely that a wind velocity of more than 30 miles an hour would be sufficient to make a conflagration possible even during or following a heavy rainstorm. It is, of course, to be appreciated that the spreading effect of wind is directional and that it can, on occasion, operate so as to protect a threatened area lying upwind from the point at which fires are initiated. There have been numerous instances of winds which have carried conflagrations over large areas and then shifted 180° so as to drive the fire back upon areas already destroyed, thereby effectively terminating it.

## CONCLUSIONS

The appalling consequences of the mass fires, which took the form of fire storms or conflagrations, were the outstanding feature of the attacks on cities in World War II.

Fire storms and conflagrations were produced by very heavy attacks concentrated in space and time which started simultaneously a large number of fires close together. Both mixed high-explosive and incendiary bombs and the atomic bomb are capable of producing such effects.

The structural arrangement of cities determines whether wartime fire attacks will produce fire storms and conflagrations. The primary factors are considered to be:

*a.* Building density.

*b.* Combustibility of structures.

*c.* Firebreaks.

*d.* Size of target area.

Contributing factors are:

*a.* Continuity of combustible construction.

*b.* Occupancy combustibility.

*c.* Size of buildings.

*d.* Topography.

Weather factors are:

*a.* Humidity.

*b.* Precipitation.

*c.* Wind.

Since the foregoing factors are all present in varying degrees in American cities, what happened in Germany and Japan could happen here. Adequate fire-control planning for civil defense will depend to a great extent on an assessment of those characteristics of built-up areas which would make them susceptible to fire storms and conflagrations. The method involves resolving the urban city areas into subareas of fairly homogeneous building density. The other factors can then be applied to those subareas to obtain an estimate of their susceptibility to fire and to the production of great mass fires.

Defining the areas of a community in these terms will not only assist in planning what to do in case of attack but will act as a guide to long-range planning designed to eliminate or reduce to a minimum the existence of highly vulnerable areas in our cities. Even if this country never suffers an attack, we will have made permanent strides toward a better America.

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