THE EFFECTS OF THE ATOMIC BOMBS AT HIROSHIMA AND NAGASAKI

❖

REPORT OF THE BRITISH MISSION TO JAPAN

HIS MAJESTY'S STATIONERY OFFICE LONDON
1946

ONE SHILLING NET

THE EFFECTS OF THE ATOMIC BOMBS AT HIROSHIMA AND NAGASAKI

REPORT OF THE BRITISH MISSION TO JAPAN

PUBLISHED
FOR THE HOME OFFICE AND THE AIR MINISTRY BY
HIS MAJESTY'S STATIONERY OFFICE
LONDON
1946

Foreword

UNTIL AUGUST, 1945, the attacks delivered from the air by the allied and associated powers on enemy countries had been of increasing intensity, but the effects from blast or fire were such that the damage from a known weight of attack could be predicted with some degree of accuracy from past experience. In the early days of August the United States Air Force attacked Hiroshima and Nagasaki with a new weapon. One atomic bomb was dropped over each city. The destructive effects in each case were on a scale which far exceeded that of previous air raids. New phenomena accompanied this form of attack and the whole problem of counter measures and civil defence generally required reconsideration.

IN THE COURSE OF THE WAR the Research and Experiments Department of the Ministry of Home Security had evolved a scientific method for the measurement of the effect of air attack in the various forms and the Home Office, as the successors of the Ministry of Home Security, as well as the Service Departments, regarded it as desirable to invite the United States Authorities to agree that a British team of experts trained in that method should co-operate with the United States Strategic Bombing Survey to conduct an investigation into the effects of the bombing of the two Japanese cities.

THE UNITED STATES AUTHORITIES provided every possible facility for the investigation, and the detailed arrangements were made by the United States Strategic Bombing Survey. In addition to factual examinations at Hiroshima and Nagasaki, the United States Authorities placed at the disposal of the British experts the records and observations which their more prolonged and detailed study had produced. In particular the part of this report which deals with the effects of atomic bombs on the human structure is based on material supplied by the Medical Section of the Joint Commission for the Investigation of the Effects of the Atomic Bomb.

BY AGREEMENT with the United States Authorities this report by the British experts is now published in this country simultaneously with the publication in America of the corresponding report of the United States Strategic Bombing Survey.

HIS MAJESTY'S GOVERNMENT consider that a full understanding of the consequences of the new form of attack may assist the United Nations Organisation in its task of securing the control of atomic energy for the common good and in abolishing the use of weapons of mass destruction.

The Members of the British Mission to Japan, who were under the direction of the Chiefs of Staff, were :—

HOME OFFICE

Professor W. N. Thomas, M.A., D.Phil., M.Inst.C.E., F.R.I.B.A.
Dr. J. Bronowski, M.A., Ph.D.
D. C. Burn, M.A., M.Inst.C.E., A.M.I.Mech.E.
J. B. Hawker, A.R.I.B.A.
H. Elder, L.R.I.B.A.
P. A. Badland, B.Sc., A.M.Inst.C.E., A.M.I.Struct.E.
R. W. Bevan, B.Sc.
F. H. Pavry, B.Sc., A.M.Inst.C.E.
F. Walley, B.Sc., A.M.Inst.C.E.
O. C. Young, B.Sc., A.M.Inst.C.E.

GOVERNMENT OF INDIA

Dr. S. Parthasarathy, D.Sc., F.Inst.P., F.R.I.C.

ADMIRALTY (DNOR)

Lieut.-Commander A. D. Evans, B.A. (R.N.V.R.)

WAR OFFICE (SA/AC)

Colonel O. M. Solandt, M.D., M.R.C.P. (Canadian Army)

AIR MINISTRY (AIR STAFF)

Group Captain A. E. Dark, C.B.E.
Squadron Leader R. G. Whitehead, D.F.C., B.A.

MINISTRY OF AIRCRAFT PRODUCTION

Group Captain F. G. S. Mitchell, O.B.E.

Contents

Introduction

1. On August 6th, 1945, shortly after 8 a.m., an American Super-Fortress flying at 30,000 feet dropped a single atomic bomb over the Japanese mercantile city of Hiroshima. The bomb exploded over the city centre. Three days later, on August 9th, just after 11 a.m., a Super-Fortress flying at the same height, which had found its primary target cloud-obscured, dropped a second atomic bomb over the industrial city of Nagasaki. This bomb exploded over the city's factory area. In Hiroshima more than four square miles of city were destroyed and 80,000 people were killed. In the smaller city of Nagasaki about one and a half square miles were destroyed and nearly 40,000 people were killed. The causes of destruction and of death differed in many points from those which had acted in the conventional raids of the past. It was clear that bombing had changed its character and its scale beyond recognition.

2. The British Mission which spent the month of November, 1945, in Hiroshima and Nagasaki had been concerned in the past with the appreciation of air raid damage in Great Britain, and subsequently on the Continent of Europe. While some of its members had for other reasons made a wartime study of Japanese conditions, it was not as a whole expert in Japanese affairs. Nor was it instructed to obtain a detailed picture of those effects of the bomb which were peculiar to Japan. The report which follows tells what was seen and what could be learnt three months after the bombing in Hiroshima and in Nagasaki. But its intention is, as it was the object of the Mission, to point to general conclusions on the effects to be expected from similar atomic bombs, should they fall outside Japan, and in particular in Great Britain. The reader should picture the destruction here set down as it would strike a city which he knows well, in its people, its houses, its public buildings, its factories and its public services.

Chapter I

THE TWO CITIES BEFORE ATTACK

3. The cities of Hiroshima and Nagasaki differed from western cities and from one another in plan, in development, and in industrial importance. These differences influenced the resulting damage and that to be expected elsewhere.

HIROSHIMA

4. Hiroshima is built on the islands and shores of the delta where the river Otagawa falls into the Inland Sea. Although hills rise to 700 feet and 800 feet to the immediate north-west and north-east, the city stretches over flat ground in all directions for roughly two miles from the centre. The city centre, once the Old Town, was dominated by a number of reinforced concrete buildings owned by banks, insurance companies, department stores, newspapers, and similar mercantile enterprises. Beyond the Old Town lay an industrial zone developed during the early part of this century, and consisting of many small wooden workshops set among dense Japanese houses. A few larger plants devoted to engineering and silk manufacture lay on the southern and western outskirts of the city. The city was a prosperous trading community having some contacts with the outside world, and its centre was spaciously planned, with fine streets and temples.

5. Like other Japanese cities, Hiroshima was growing rapidly before the war ; its census population rose from 270,000 in 1930 to 345,000 in 1940. It remained at this figure for the greater part of the war, but began to fall in 1944, and at the time of the attack it was below 245,000. This fall was the result of evacuation, in the main compulsory and accompanied by the systematic destruction of houses to form fire breaks. This programme, which had been given impetus by the great incendiary raids on Tokyo and other Japanese cities in the second week of March, 1945, was only partly completed when the atomic bomb fell.

6. The census figures quoted are probably what Japanese call the " registered " population, used for such purposes as rationing. This is usually thought to be about 80 per cent. of the actual population which, with about 10,000 troops, and perhaps 5,000 workers brought in to cut fire breaks, may therefore have been as high as 320,000 at the time of the attack. This is approximately the pre-war population of Hull or the Borough of Islington. But Hiroshima is naturally more straggling than the latter, and covers altogether an area of over ten square miles.

NAGASAKI

7. Nagasaki lies on the more southerly Japanese island of Kyushu, at the head of a long bay which forms its natural harbour. The western shore is occupied by port facilities, shipbuilding and repair, and the eastern shore by smaller shipyards, wharves and dwellings. The main commercial and residential area of the city lies on a small plain near the head of the bay on its eastern shore. From here the valley of the river Urakami runs north for three or four miles, and a smaller valley branches north-east for less than two miles, making a total area of about four square miles. Both valleys are narrow, and are separated and flanked by abrupt hills rising in places to 1,000 feet.

The smaller valley is crowded with dwellings without plan, huddled around narrow roads, market streets and temple squares. The Urakami valley contained large steel, engineering, and armament works, together with smaller factories and a host of home workshops with an attendant jostle of workers' dwellings. These industries, controlled by the firm of Mitsubishi, plainly dominated Nagasaki, where everything which survives bears the stamp of a vast industrial slum. In the spring of 1945 some dispersal was begun to workshops set up for the purpose in tunnels and schools. The latter, constructed in reinforced concrete, were among the few imposing buildings in Nagasaki. The city did, however, possess a complex of modern hospital and medical school buildings of which any European city of its size might be proud.

8. Nagasaki had at one time been a naval base, and its importance had declined with the development of the base at Sasebo. Its population had risen only slowly between 1930 and 1940, when the census population was 253,000, but had gone on rising during the war, which gave new importance to its shipbuilding and its production of torpedoes and other armaments. As at Hiroshima, there was large-scale evacuation from March, 1945. Calculating in the same manner as at Hiroshima, it is estimated that the population actually in Nagasaki when the bomb fell was just over 260,000. This is roughly the pre-war population of Portsmouth or of Newcastle-on-Tyne.

Chapter II

THE TWO CITIES AFTER ATTACK

HIROSHIMA

9. Eye-witnesses in Hiroshima were agreed that they saw a blinding white flash in the sky, felt a rush of air and heard a loud rumble of noise, followed by the sound of rending and falling buildings. All also spoke of the settling darkness as they found themselves enveloped by a universal cloud of dust. Shortly afterwards they became aware of fires in many parts of the city.

10. The city had been virtually undamaged by air attack before the atomic bomb fell. The bomb exploded near its centre over a point approximately 300 yards from the T-shaped double bridge which is a conspicuous feature of Hiroshima ; and thence spread its destruction with great uniformity. Directly or indirectly, it initiated innumerable fires among the wooden houses and workshops, which burned unchecked for days and gutted the Old Town and the industrial zone enclosing it. The more modern industrial buildings on the edge of the town, however, at 1½ miles and more from the centre, escaped with only minor damage. There are contradictory accounts of whether the fire service did or did not attempt to fight fires in the first twelve hours ; but no civilian defence services in the world could have met a disaster on this scale, and these services were in fact overwhelmed. On August 6th, the authorities in Hiroshima were making preparations to meet what they believed to be a threatened incendiary attack : they were not prepared for a holocaust.

11. As photographs 1 and 2 show, Hiroshima today has the appearance of a burnt city. The traveller who comes to it from the Japanese cities which have been razed by incendiary attack, Tokyo, Kobe, Osaka and others, sees the same unending stretches where wooden buildings have burned to the very ground, broken only by a few shacks newly built from salvaged iron sheeting, by tall chimneys which mark the sites of burnt-out public baths, and by concrete buildings, the shells of which alone have survived the fires.

Photos Nos. 1 and 2. HIROSHIMA. General views looking across the centre of damage, the approximate position of which is marked with an arrow. It will be seen that some of the framed buildings quite near the centre remained standing. The tall building in Photo No. 1 is the same as that seen in Photo No. 7. The foreground illustrates the remnants of Japanese dwellings, razed to the ground. See paragraph 11.

NAGASAKI

12. A detailed description of the attack on Nagasaki was prepared by the Prefect for the Japanese government on September 1st. His report begins with an uncertain account of the state of alert : an Alert which had been sounded earlier had been " relaxed ", but probably there had been no final All Clear. This would conform with the Japanese practice of " relaxing " but not cancelling an Alert when only a few enemy planes were in the neighbourhood. The same conditions probably obtained during the attack on Hiroshima. The report goes on to describe the dropping of three parachutes which preceded the bomb, the bright flash of the explosion in the sky, followed by a haze of white smoke which darkened rapidly ; and the accompanying roaring sound, with some feeling of pressure and wind and of heat.

13. The Nagasaki Prefect's report describes the bomb as " aimed at the industrial plants in the northern part of the city ". The centre of damage is in fact in the industrial area between the two large Mitsubishi Ordnance Plants in the Urakami Valley. Hence the harbour and the commercial area, nearly two miles distant, escaped with only minor damage; and so did the housing in the smaller valley, screened by the intervening ridge of hills.

14. For these geographical reasons the area of damage and with it the death roll were naturally smaller than in Hiroshima. This caused the Japanese first to report the bomb as a smaller version of the Hiroshima model.

15. The few previous attacks on Nagasaki had been aimed at the shipyards, so that most of the damage from them is outside the area of atomic bomb damage. As in Hiroshima, the initial blast damage done by the atomic bomb was followed by extensive fires, which here spread somewhat more slowly. But where the area burnt out in Hiroshima was compact, in Nagasaki it is broken by long lines of factory sheds, leaning their steel skeletons eerily away from the explosion (see photographs 4 and 6). Within the factories, rows of machines stand in a sea of tiles, corrugated sheeting, and timber roof boards ; fuze-boxes, switchboards, and gear cases blown open and torn from their moorings hang, fantastically supported by the remnants of their fittings ; and the whole is festooned by the tangled service systems of wire, steam and gas piping. Furnace doors blown open show the cold mass of the last charge under the brickwork of the fallen furnace roof. Over a wide area such blast-resistant objects as telegraph poles and tram and electricity standards lean away from the bomb; on the surrounding hills, trees have been blown down at large distances. Thus Nagasaki presents the appearance of a city struck by a brief but tremendous hurricane.

EFFECT ON CITY LIFE

16. Both in Hiroshima and in Nagasaki, the scale of the disaster brought city life and industry virtually to a standstill. Even the most destructive conventional attacks, the incendiary raids on Hamburg in the summer of 1943 and on Tokyo in the spring of 1945, had no comparable effect in paralysing communal organization. Witnesses report a panic flight of population, in which officials and civil defence personnel joined, abandoning even the rescue services. All large-scale effort had to await the return of population, which was slow; there were still only 140,000 people in each city at the end of November. Even the clearance of debris and the cremation of the dead trapped in it do not seem to have been begun for more than a month, and members of the Mission still stumbled upon undiscovered skeletons. Allowance must no doubt be made for the moral

Photo No. 3. NAGASAKI. A general view of the area near the centre of damage, which is to the left in the picture, only 300 yds. away from the bridge. Note the little that remains (in the foreground) of blasted and burnt Japanese dwellings. For a view of such houses, undamaged, see Photo No. 19.

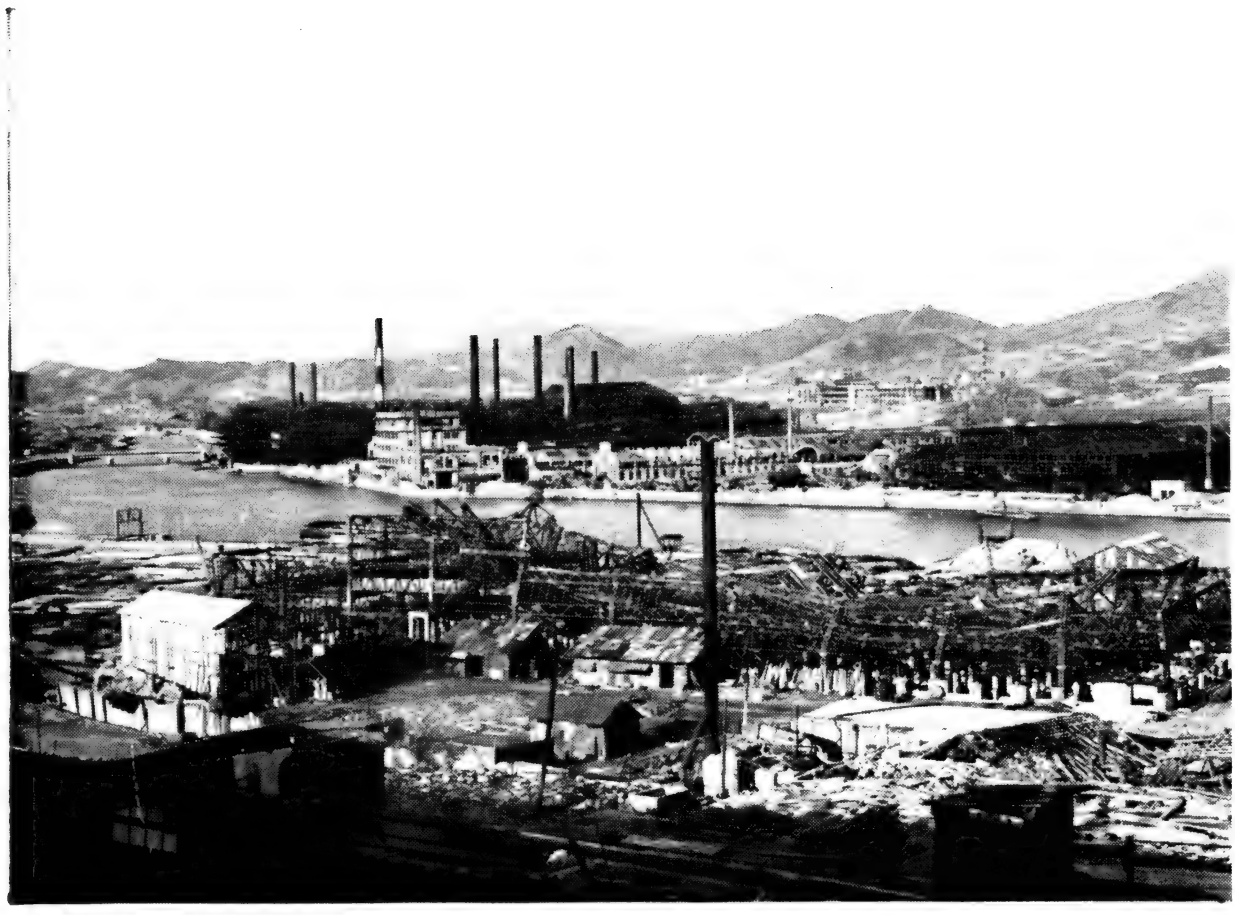

Photo No. 4. NAGASAKI. A general view showing some of the industrial buildings. That in the foreground was a gutted woodworking plant, just over a mile from the centre of damage, which was beyond the group of chimneys of the Mitsubishi Steel Works, seen in the middle distance. See paragraph 15.

effect of the end of the war, which had removed the backbone of communal incentive. And some tribute should be paid to isolated feats of restoration, such as that of electricity to Nagasaki and later that of the trams in Hiroshima. Nevertheless, the larger impression which both cities make is of having sunk, in an instant and without a struggle, to the most primitive existence. Among causes which are likely to operate outside Japan were the death of key personnel, the destruction of public services, and the destruction of housing. In Nagasaki alone the Prefect reported 60,000 homeless, and 25,000 living in damaged houses. As photograph 16 shows, the construction of some form of shelter is a major preoccupation of nearly all those who have returned. It is plain that local services are unequal to dealing with such disasters, either immediately or later, and that planned and energetic action by central government is essential.

Chapter III

THE ACTION OF THE ATOMIC BOMB

17. It was officially announced by President Truman at the time of the Hiroshima attack that the explosive energy of the bomb was equivalent to that of 20,000 tons of T.N.T. Estimates of the equivalent amount of T.N.T. were made by the Mission, based on the damage observed and on extrapolation from experience with much smaller charges. The blast damage was judged to be somewhat less than would have been expected from 20,000 tons, particularly at Hiroshima. This effect may have resulted from the present uncertainties regarding the extent to which damage per ton of explosive falls off as the weight exploded increases.

18. The source and the manifestation of energy in the atomic bomb differ from those in conventional explosions. The energy stored in an explosive such as T.N.T. is chemical, and when liberated is used in the rapid conversion of the explosive to a gas. This gas, seeking to occupy a volume many times larger than did the solid explosive, exercises intense pressure on the surrounding air, which in turn passes it on to the next layer of air, and so on. The belt of high pressure thus rapidly moving outward from the explosion is the blast wave, and is the major cause of damage from high explosive. All explosions also release heat, but its contribution to the damaging effect is usually negligible.

19. In the process of atomic fission energy is actually created by the destruction of an infinitesimal fraction of the material which is undergoing fission. Some of this energy is communicated to the products of fission, and to the bomb case, but the greater portion is communicated to the surrounding air, which is thereby raised to an extremely high temperature. As a result, the air expanding under the influence of this temperature rise exerts enormous pressure. This pressure moves outward as a blast wave in the conventional manner.

20. At the same time a further large part of the energy created in atomic fission is radiated. This radiation is of various wave lengths including that of ordinary light, and also heat radiation, that is, radiation of longer wave length, and X-rays and possibly gamma rays, that is, radiation of shorter wave length than that of light. Heat radiated by the atomic bomb (which should not be confused either with flame or with heated air) and penetrating short wave radiations are intense enough to kill thousands of people. By contrast, conventional explosions release no penetrating radiation, and the heat released is dangerous only at small distances—for example, to gun crews exposed to the flash at the mouth of a gun.

Photo No. 5. NAGASAKI. Reinforced concrete school with a timber roof, 500 yds. from the centre of damage, which is to the right of the photograph. The upper part of the long wall further from the explosion has been bent over, partly by a thrust through the roof from the other long wall and partly by wind suction. This is a typical case of " mass distortion." See paragraphs 15 and 22.

Photo No. 6. NAGASAKI. Mass distortion of steel framed shed buildings about half a mile from the centre of damage, which was to the right of the buildings in the photograph. It will be seen that the entire main frame is seriously distorted away from the explosion. See paragraphs 15, 22 and 32.

Photo No. 7. HIROSHIMA. Reinforced concrete building about 300 yds. from the centre of damage, which is to the left of the photograph. There was no serious structural damage, although a roof panel was depressed and some internal party walls were deflected. Designed for earthquake resistance, this building has a composite reinforced concrete and steel frame. See paragraph 24.

Photo No. 8. HIROSHIMA. Reinforced concrete building 200 yds. from the centre of damage, which is to the right. The blast from the bomb forced the roof slab down, the slab shearing round the column heads, leaving the internal columns projecting through the debris. Few concrete buildings failed in this way. See paragraph 24.

Chapter IV

BLAST EFFECTS

SCALE AND KIND OF EFFECT

21. As mentioned in the previous chapter it is difficult to estimate the equivalent amount of T.N.T. from the damage caused in Hiroshima and Nagasaki, because the criteria are very insensitive. It may suffice, however, to point out that an explosion of 20,000 tons of T.N.T. would be expected to cause at a distance of ½ mile from the centre of damage an instantaneous pressure rise of about 10 lb. per square inch, falling back to atmospheric pressure in about ½ second : and since, during part of this time, there would be a wind of the order of 500 miles an hour, the pressure initially imposed on parts of a building might be as high as 30 lb. per square inch. Such figures could be multiplied and become meaningless : the reader who finds them so may prefer a summary analogy. This is that the scale of destruction expected would be that which would befall a model town built to the scale of Gulliver's Lilliput, 1 inch to the foot, if there were exploded above it a bomb more than twice as large as the largest British " blockbuster ", which with its case weighed about six tons.

22. This model and what has been said will also help him to understand the major differences between conventional blast effects and those seen in Hiroshima and Nagasaki. These were three in number.

Mass Distortion.—It is usual for a bomb to damage only part of a large building, which may then collapse further under the action of gravity. The blast wave from the atomic bomb, however, was so large that it engulfed whole buildings, pushing them askew in the manner shown in photographs 5, 6,11 and 12. The effect, which occurred with all types of buildings, resembles damage done by wind, and operates somewhat in the same way. Thus the pressure which damaged the long wall in photograph 5, which shows the side remote from the explosion, was transmitted in part from the front wall through the roof and floors, and in lesser part was the wind suction which is normally felt on the leeward side of an obstacle.

Infrequency of Blast Suction.—After the blast pressure has fallen from its peak back to zero, there always follows a period of suction (unrelated to the wind suction just mentioned). Although this suction is weaker than the original pressure, it lasts several times as long, and therefore normally does much damage to objects which had no time to fail under the usually brief initial pressure. Pressures from the atomic bomb, however, lasted long enough to give windows, doors, walls, and even chimneys and telegraph poles time to fail. As a result, effects which could be ascribed to blast suction were unusually scarce, although a few were observed in Hiroshima.

Downward Thrust.—Because the explosion was high in the air, much of the damage was due to downward pressure. Most characteristic was the " dishing " of the flat roof slabs of reinforced concrete buildings, some of which assumed a saucer shape. For the same reason, telegraph and other poles remained upright immediately below the explosion, but were overturned or tilted at greater distances from the centre of damage. Trees below the explosion remained upright, but had their branches torn downward.

23. Screening from blast by large features, and similar effects, were not unusual ; for example, almost the whole of the smaller valley in Nagasaki was screened by the intervening mountain ridge. The reflection of blast, which adds considerably to its force, was unusually marked but important only in special cases, among them some bridges. Finally there may be remarked the absence of the carriage of any heavy debris over large distances. Small debris such as tiles and battens appeared to have been carried considerable distances, and was found on tall buildings. But larger pieces of debris were always found close to their point of origin, and where massive slabs such as bridge decking had been shifted, the movement, although on occasion critical, was small.

DAMAGE TO COMMERCIAL AND INDUSTRIAL BUILDINGS AND MACHINES

24. Photographs in this report and elsewhere show great areas of destruction in which, rising here and there like islands, there remain reinforced concrete buildings showing few signs of external damage. There were in fact many reinforced concrete buildings in Hiroshima and a number in Nagasaki. They varied from exceptionally strong office blocks (see photograph 7) designed to be proof against earthquake, to lightly constructed industrial buildings (see photograph 10). Between these extremes were some schools and office buildings of more or less normal design such as is usual in Great Britain. In comparison with other forms of construction these buildings resisted the blast well. Owing to the height of the explosion, the behaviour of buildings near the centre of damage was greatly influenced by that of their roofs.

25. For example, the building of normal construction shown in photograph 8 collapsed at 200 yards from the centre of damage because the flat roof was forced in. The Nagasaki school shown in photograph 5, which suffered mass distortion at 500 yards from the centre of damage, while it had special weaknesses, may also be regarded as of roughly normal design. At 700 yards from the centre of damage in Nagasaki, another school of normal design suffered some structural damage, but did not collapse and one wing continued in use. A school and an office block, each at $\frac{3}{4}$ mile from the centre of damage, remained structurally sound, although some internal walls were damaged. In summary, reinforced concrete buildings of normal construction were usually safe from partial collapse beyond 600 yards from the centre of damage, and from structural damage beyond $\frac{1}{2}$ mile.

26. Reinforced concrete buildings of very heavy construction in Hiroshima, even when within 200 yards of the centre of damage, remained structurally undamaged. Flat roof slabs 6 ins. or 7 ins. thick were often dished, but a roof thickness of 10 ins. appeared to be sufficient to resist permanent deflection.

27. It is appropriate here to draw attention to the building the interior of which is shown in photograph 9. This was less massive than the strongest Hiroshima buildings, but its design incorporated features which made it unusually resistant to side pressure. As a result it remained structurally undamaged, although only 500 yards from the centre of damage.

28. These observations make it plain that reinforced concrete framed buildings can resist a bomb of the same power detonated at these heights, without employing fantastic thicknesses of concrete. The main requirements are a frame designed to withstand heavy side forces from any direction, and

Photo No. 9. HIROSHIMA. Reinforced concrete school 500 yds. from the centre of damage, which is to the right. The frame of this building was of special design (portal) and resisted the lateral forces. The outside walls were of continuous reinforced concrete, and although they were deflected, as seen, they did not fail. See paragraph 27.

Photo No. 10. NAGASAKI. Reinforced concrete single storey factory rather less than a mile from the centre of damage, which is to the right. The arched reinforced concrete roof failed, the side nearer the explosion being forced inwards and the far side forced upwards. See paragraphs 24 and 29.

Photo No. 11. HIROSHIMA. Small steel framed shed $\frac{1}{4}$ mile from the centre of damage, showing the distortion of the entire framework, with the building leaning away from the explosion. See paragraphs 22 and 32.

Photo No. 12. NAGASAKI. Large steel framed shed in the Mitsubishi Steel Works, $\frac{3}{4}$ mile from the centre of damage. The steel stanchions have been bent (away from the explosion) and the roof trusses on both sides of these stanchions have collapsed. See paragraphs 22 and 32.

a flat reinforced concrete roof perhaps 50 per cent. thicker than would be normal practice. The reinforcement of external concrete walls should also be tied into the supporting frame. It is believed that similar requirements would suffice for steel framed multi-storey buildings, of which Nagasaki contained the only example. These requirements ignore fire and casualty risks, which are dealt with later.

29. Light single-storey concrete buildings, such as are employed for factories (see photograph 10) and warehouses, failed at about a mile from the centre of damage in both cities.

30. Of the industrial buildings seen, those most characteristic of western practice were the steel framed single-storey factory sheds. Useful examples were confined to Nagasaki, where they were plentiful throughout the Urakami valley both north and south of the centre of damage. They were usually of the type found in large engineering works, with travelling cranes and a covering of thin corrugated iron or asbestos cement sheeting.

31. The bulk of the damage to these buildings was by blast. In Nagasaki fire had contributed to the damage in only about 10 per cent. of cases of damage. In Hiroshima the few small steel framed sheds found had been damaged further by fire, but this had probably originated in the wooden houses by which they were there surrounded.

32. The most striking feature of damage was the mass distortion, in the direction away from the explosion, of the entire framework of these buildings. This distortion, which is shown in photographs 6, 11 and 12, occurred at distances up to more than $\frac{3}{4}$ mile from the centre of damage. Its amount naturally decreased with the distance from the explosion. Distortion appeared to be less severe in sheds which had been covered with a material which had itself shattered under the blast, such as asbestos cement, than in sheds which had been covered with a pliable material such as corrugated iron, which had transmitted the pressure. (Roof and wall coverings of both types were destroyed to distances of 2 miles and more from the centre of damage.) Beyond the range of mass distortion, steel framed sheds suffered damage to the structural framework at distances up to roughly $1\frac{1}{4}$ miles from the centre of damage. Like other buildings, sheds suffered more severely when they had a long wall facing the blast, or if they lacked stiffness or bracing.

33. Of the machines housed in these sheds, only 5 per cent. had suffered serious damage from the atomic bomb. This low figure is to be ascribed to the absence of fire, so that damage was caused only by the movement of parts of the structure which crushed or overturned adjacent machinery. The Japanese had, however, allowed the undamaged machines to weather in the damaged buildings without protection, with the result that the majority had become unserviceable.

34. Nearly two-thirds of all machines in the Urakami valley had been housed in smaller workshops and sheds of timber. These shops were burnt down almost without exception to a distance in excess of $1\frac{1}{4}$ miles from the centre of damage. As a result 50 per cent. of the machines housed in these shops were destroyed or irreparably damaged. Their appearance today is shown on photograph 13.

35. Little information could be obtained on machines housed in reinforced concrete sheds with thin concrete roofs, a type of factory construction more common in Europe than in Japan. Such evidence as was found suggests that approximately 75 per cent. of the machines in such sheds (the vulnerability of which has been remarked in paragraph 29) would have suffered damage from the heavy debris formed by the collapsing roof.

36. Reference has been made to timber framed single-storey buildings, which were common as workshops and warehouses both in Hiroshima and Nagasaki. These buildings behaved badly, being excessively vulnerable both to fire and to blast. For example, the absence of internal stiffening, and the great weight of the roof trusses and tiles, made them subject to collapse from mass distortion at distances of 2 miles and more from the centre of damage.

DAMAGE TO HOUSES AND SHELTERS

37. The bulk of the damage in both cities, naturally, was to Japanese houses. These houses are constructed on a frame of 4 ins. or 6 ins. square timbers. The roofs are not trussed in the orthodox manner and are a source of weakness, particularly since their covering of pantiles bedded in mud on $\frac{1}{2}$ in. boarding is disproportionately heavy. The walls are of bamboo covered with 3 ins. of mud, which is sometimes protected by $\frac{1}{4}$ in. boarding ; but as photograph 19 shows, much of the wall space is occupied by paper-covered screens. Complete collapse of these buildings from blast extended to $1\frac{1}{4}$ miles from the centre of damage in Hiroshima, and to an average of $1\frac{1}{2}$ miles in Nagasaki. Fire completed the destruction almost to the same distance, except in one congested area of Nagasaki, where it exceeded it. Beyond the region of complete collapse damage decreased rapidly, the further zone in which houses had been damaged beyond repair being little more than $\frac{1}{4}$ mile wide. Minor damage extended to large distances, 3 miles or more from the centre of damage.

38. Naturally, the subject of major interest outside Japan is the behaviour of unframed brick buildings with load-bearing walls, which make up the bulk of European housing. These buildings are rare in Japan, and those which were found differed in important respects from British housing. The Mission had therefore to draw its conclusions from such isolated examples as that shown in photograph 15. (This building, although somewhat stronger than British houses, had collapsed at 700 yards from the centre of damage.) Interpreting such examples in the light of its European experience, the Mission estimated that a bomb of the same power, exploding at the approximate height of those in Hiroshima and Nagasaki,

would cause the collapse of normal British houses to a distance of 1,000 yards from the centre of damage ;

would damage them beyond repair to a distance of 1 mile ;

would render them uninhabitable without extensive repair, particularly to the roof timbers, to a distance of $1\frac{1}{2}$ miles ;

and would render them uninhabitable until first-aid repairs had been carried out, to a distance of 2 to $2\frac{1}{2}$ miles from the centre of damage.

39. Unframed masonry construction with load-bearing walls of greater thickness is also widely employed throughout Europe for public buildings and blocks of flats. Such buildings are subject to damage of equal severity, at

Photo No. 13. NAGASAKI. ½ mile from centre of damage. Typical damaged machines in one of the many timber workshops destroyed by blast and fire. Some machines were overturned by movement of the buildings, some destroyed by fire alone ; others damaged by exposure to the weather. See paragraph 34.

Photo No. 14. NAGASAKI. Blast effect on a gasholder ½ mile from centre of damage. Note the way in which the whole framework has been bent away from the explosion. See paragraph 43.

Photo No. 15. HIROSHIMA. Three storey bank building with load-bearing brick walls of strong construction and comparable with British standards. This degree of damage to such buildings extends to a radius of ½ mile from centre of damage. Compare with the behaviour of the reinforced concrete framed building in the background. See paragraph 38.

Photo No. 16. NAGASAKI. The Roman Catholic Cathedral 600 yds. from centre of damage. The walls were of heavy load-bearing brick construction. Most of the damage is attributable to blast, although fire subsequently consumed all combustible debris. Note in the foreground the huts erected by the Japanese for temporary living quarters after the atomic bomb raid. See paragraphs 11, 16 and 39.

smaller but considerable distances. Photograph 16 shows the damage to the monumental Roman Catholic Cathedral of Nagasaki at 600 yards from the centre of damage. Here the damage was completed by fire and other causes, but effectively the building had already been destroyed by blast.

40. The provision of air raid shelters throughout Japan was much below European standards. Those along the verges of the wider streets in Hiroshima were comparatively well constructed : they were semi-sunk, about 20 ft. long, had wooden frames, and 1 ft. 6 ins. to 2 ft. of earth cover. One is shown in photograph 17. Exploding so high above them, the bomb damaged none of these shelters.

41. In Nagasaki there were no communal shelters except small caves dug in the hillsides. Here most householders had made their own backyard shelters, usually slit trenches or bolt holes covered with a foot or so of earth carried on rough poles and bamboos. These crude shelters, one of which is shown in photograph 18, nevertheless had considerable mass and flexibility, qualities which are valuable in giving protection from blast. Most of these shelters had their roofs forced in immediately below the explosion ; but the proportion so damaged had fallen to 50 per cent. at 300 yards from the centre of damage, and to zero at about $\frac{1}{2}$ mile.

42. These observations show that the standard British shelters would have performed well against a bomb of the same power exploded at such a height. Anderson shelters, properly erected and covered, would have given protection. Brick or concrete surface shelters with adequate reinforcement would have remained safe from collapse. The Morrison shelter is designed only to protect its occupants from the debris load of a house, and this it would have done. Deep shelters such as the refuge provided by the London Underground would have given complete protection.

DAMAGE TO PUBLIC SERVICES

43. It remains to discuss the behaviour of the major public services. Many of these are subject to the consideration which has been implied in the discussion of shelters : that bombs exploded at such heights have no effect below ground. For example, gas and water pipes were in general undamaged except where they were carried over rivers on bridges which were displaced. Sewers were undamaged in Hiroshima ; they did not exist in Nagasaki. However, in both cities the gas supply was destroyed by severe damage to the gas holders (see photograph 14) up to $1\frac{1}{4}$ miles from the centre of damage. The producing plant was not seriously damaged at this distance. In both cities, the water pumping station was beyond the range of damage, but that at Hiroshima was out of action for some weeks for lack of electric power.

44. Overhead electricity, tramway, telephone, and telegraph cables and their supports were severely damaged to distances of $\frac{1}{2}$ mile to 1 mile. In addition, the electricity supply was affected by damage to sub-stations, resulting in debris damage to the switchboards and switchgear ; such damage was serious, for example, in the main transformer station in Nagasaki, 1 mile from the centre of damage. The great dispersal of the Japanese electricity system, however, made it possible to supply current to most undamaged areas in Nagasaki within a fortnight.

45. Damage to public transport was not considerable. Railway and tramway tracks were only indirectly affected, by debris, adjacent fire, overturned rolling stock and displaced bridges. The Prefect of Nagasaki reports that slow-running trains reached the city along the main railway line, which runs within 100 yards of the centre of damage, three days after the bombing. Trams, buses, and motor cars were probably destroyed to distances of ½ mile to 1 mile from the centre of damage, and some tram motors were reported to have been burnt out beyond 2 miles. Fuel storage tanks were damaged beyond repair more than 1 mile from the centre of damage.

46. There were 49 bridges within 2 miles of the centre of damage in Hiroshima. Most of these were multiple girder bridges in steel or reinforced concrete, and many had one or more suspended spans ; their overall length was usually between 200 ft. and 500 ft. Only one wooden bridge, and one steel bridge in bad repair, were destroyed by the blast ; and nine wooden bridges were burnt down in the subsequent fires. The remaining bridges were usable, although some of them had suffered small displacement in the direction away from the explosion, having perhaps been lifted by blast reflected from the river bed. Seven of these bridges were destroyed by two floods before the Mission reached Hiroshima.

47. The 35 bridges within 2 miles of the centre of damage in Nagasaki were all small and relatively light. As a result, all bridges within ½ mile of the centre of damage suffered some damage or displacement, most severe in the least massive bridges, but in only four cases did the damage require repair (in two cases, extensive repair) before the bridge could be used. This excellent behaviour in both cities is associated with the fact that bridges, almost alone among the structures which have been discussed, are designed for vertical loads such as resulted from the high burst of the bombs.

Chapter V

HEAT EFFECTS

FLASHBURN

48. It has been explained in paragraph 20 that some of the energy which is created in the process of atomic fission is radiated as heat, on a scale immensely larger than the heat flash released by a conventional explosion. A wide range of materials was affected by the high temperature and heat flow which resulted from this heat radiation in Hiroshima and Nagasaki. These effects on any material subject to scorching are called *flashburn.*

49. Photograph 21 shows the manner in which heat has roughened the surface of polished granite, which retains its polish only where it has been shielded from the radiation (which travels in straight lines from the explosion), for example by the man who was evidently sitting on the stone at the instant of the explosion. This roughening is caused by the unequal expansion of the constituent crystals of the stone ; for the quartz crystals this becomes critical somewhat below 600° C. Therefore the depth of roughening and ultimate flaking helps to determine average ground temperatures in the instants following the explosion. Such roughening extended about 1½ times as far in Nagasaki as in Hiroshima.

Photo No. 17. HIROSHIMA. Typical, part below ground, earth-covered, timber framed shelter 300 yds. from the centre of damage, which is to the right. In common with similar but fully sunk shelters, none appeared to have been structurally damaged by the blast. Exposed woodwork was liable to " flashburn." Internal blast probably threw the occupants about, and gamma rays may have caused casualties. See paragraph 40.

Photo No. 18. NAGASAKI. Typical small earth-covered back yard shelter with crude wooden frame, less than 100 yds. from the centre of damage, which is to the right. There was a large number of such shelters, but whereas nearly all those as close as this one had their roofs forced in, only half were damaged at 300 yds., and practically none at half a mile from the centre of damage. See paragraph 41.

Photo No. 19. NAGASAKI. Typical Japanese houses in a street screened from damage by the surrounding hills. Buildings of similar construction formed the main proportion of buildings in Nagasaki and Hiroshima. See paragraphs 37 and 80.

Photo No. 20. NAGASAKI. A room in the concrete hospital, $\frac{1}{2}$ mile from the centre of damage. The building was structurally undamaged, and one of the few of its type to escape internal fire damage. The collapse of suspended ceilings, partitions, etc., caused many casualties ; fire would have increased their plight. See paragraphs 68 and 80.

50. The Japanese commonly employed two kinds of roof tiles, on both of which the heat flash raised characteristic bubbles. These were largest where the radiation was most intense, that is, either where the tile was closest to the explosion or, as in photograph 24, where it faced the radiation squarely. This effect will serve to give independent estimates of ground temperatures. It extended nearly $1\frac{1}{2}$ times as far in Nagasaki as in Hiroshima.

51. Among miscellaneous materials affected by heat radiation were the bronze of the ceremonial animals guarding a Shinto temple, immediately below the explosion in Hiroshima ; the asphalt surface of roads, which retained the " shadows " of those who had walked there at the instant of the explosion, objects of macabre interest and pilgrimage for visitors ; and concrete and mortar renderings of buildings, which had flushed to various shades of pink.

52. As photograph 22 shows, unpainted wood displayed the most striking flashburns. These ranged from a just perceptible deepening of the natural colour, which could be observed on telegraph poles at nearly two miles from the centre of damage, through progressive scorching to complete superficial charring at small distances, where isolated timbers had sometimes been fired. Painted wood was also scorched, with no discernible selection of colours. In all timbers, the soft portions of the annual rings were most deeply charred.

53. Some paints were also directly affected, the most sensitive being the black coating on gas holders, where, as photograph 23 shows, exposure to heat radiation gave a polished appearance to the original dull and sooty finish.

54. In all these cases, " shadows " were cast by intervening objects where they shielded a part of the otherwise exposed surface from the direct heat radiation. In the shadow, the surface retained its original state ; outside it, across a more or less sharply defined boundary, it was scorched. When neither the shielding object nor the scorched surface had moved, as in photograph 23, it was therefore possible to determine the direction from which the radiation had come. A number of such determinations then served to fix the position of the explosion. This procedure had already been used by the Japanese and others, and there was reasonable agreement between the determinations.

55. Where shadows were susceptible to precise measurement, for example the shadows of vertical or horizontal bars, they were usually found to be narrower than the shielding obstruction. In particular, there could be observed the striking phenomenon of the complete disappearance of the shadows of narrow objects at sufficient distances from the scorched surface. For example, on a bridge in Hiroshima the lowest of three equal and parallel sets of bars had cast a well-defined shadow, and the middle a perceptible one, but the highest none. The main cause of this effect was probably the finite size of the radiating fire ball.

56. There were cases where a clump of grass or the leaf of a tree had cast a sharp shadow on otherwise scorched wood. Therefore the most intense flash from the ball of fire had ended in a time less than that required to shrivel vegetation. On the other hand, since direct injuries to the eye-ball were not common, the heat radiation may be presumed to have required a perceptible time to build up to its maximum intensity, during which some people had closed their eyes.

57. A phenomenon more striking than important, but which attracted wide attention, was the charring of darker patches on fabrics at distances from the explosion at which lighter patches were no longer charred. Among the materials which the Mission examined in Hiroshima, by the courtesy of the Medical Section of the Joint Commission for the Investigation of the Effects of the Atomic Bomb, were:—

A white cotton blouse the pale pink sleeves of which were patterned with small sprays, each about $\frac{3}{16}$ in. in diameter, of green leaves and red flowers. This blouse had been worn in the open well over a mile from the centre of damage, and was unscorched; except that over an area on the left shoulder the sprays alone had been burnt out and had left holes. Over a larger surrounding area the sprays had begun to burn, and here the red flowers had smouldered markedly earlier and more extensively than the green leaves.

A white dress, unscorched except for its blue polka dots, which had been burnt out over a large area. On the edges of this area the dots had begun to smoulder, each from its centre outward.

A shirt of alternate dark and light grey stripes, each about $\frac{1}{8}$ in. wide, over an area of which the dark stripes were completely burnt out but the light stripes remained.

A kimono patterned with white lozenges on a blue ground, large areas of which were burnt and had had to be beaten out. This garment like many others was said to have been fired directly by heat radiation. On the edges of its burnt area, the white lozenges had survived and only the blue ground had been burnt. Considering this in the light of the preceding exhibits, the story of its flash ignition appears reasonable.

A piece of Japanese paper exposed nearly $1\frac{1}{2}$ miles from the centre of damage, on which characters written in black ink had been neatly burnt out.

These effects are in line with known experimental facts: for example, that black cotton begins to char at temperatures perhaps 30° C. lower than does white cotton. They may be the result of differences in colour, in colouring matter, or both. These effects are interesting but not important, because they can occur only where the heat radiation is falling just below the intensity which would fire the fabric as a whole.

58. Witnesses say that people who were directly under the explosion in the open had their exposed skin burnt so severely that it was immediately charred dark brown or black : these people died within minutes or at most hours. Both in Hiroshima and in Nagasaki, burns on exposed skin were very severe up to about 1,500 yards from the centre of damage. At this distance, some escaped with less severe burns, although very severe burns were occasionally reported at nearly $1\frac{1}{2}$ miles from the centre of damage. Mild burns extended to distances of $2\frac{1}{2}$ miles and more. Stories that white people were unharmed in Hiroshima where the darker skinned Japanese received fatal burns were not substantiated.

59. In general, even thin clothing protected from flashburn. There were a few exceptions, when the skin was burnt through uncharred fabric where the latter was stretched tightly, say over the point of the shoulder. On other occasions, equally rare, clothing caught fire without burning the skin. But in general the correspondence between charred clothing and skin was close ; for example, the girl wearing the flowered blouse described in paragraph 57 had burns, some of them severe, only where the sprays had burnt.

Photo No. 21. HIROSHIMA. Roughening of polished granite by " flash " heat effect at 200 yds. from the centre of damage. The polish remains only where shielded by (*a*) a man seated on the steps, (*b*) a man leaning against the corner of the plinth adjoining the steps and (*c*) in the " shadows " of the plinth mouldings. See paragraph 49.

Photo No. 22. NAGASAKI. Timber framing scorched by heat radiation at ¾ mile from the centre of damage. The surface is unscorched where it is shielded by the uprights. See paragraph 52.

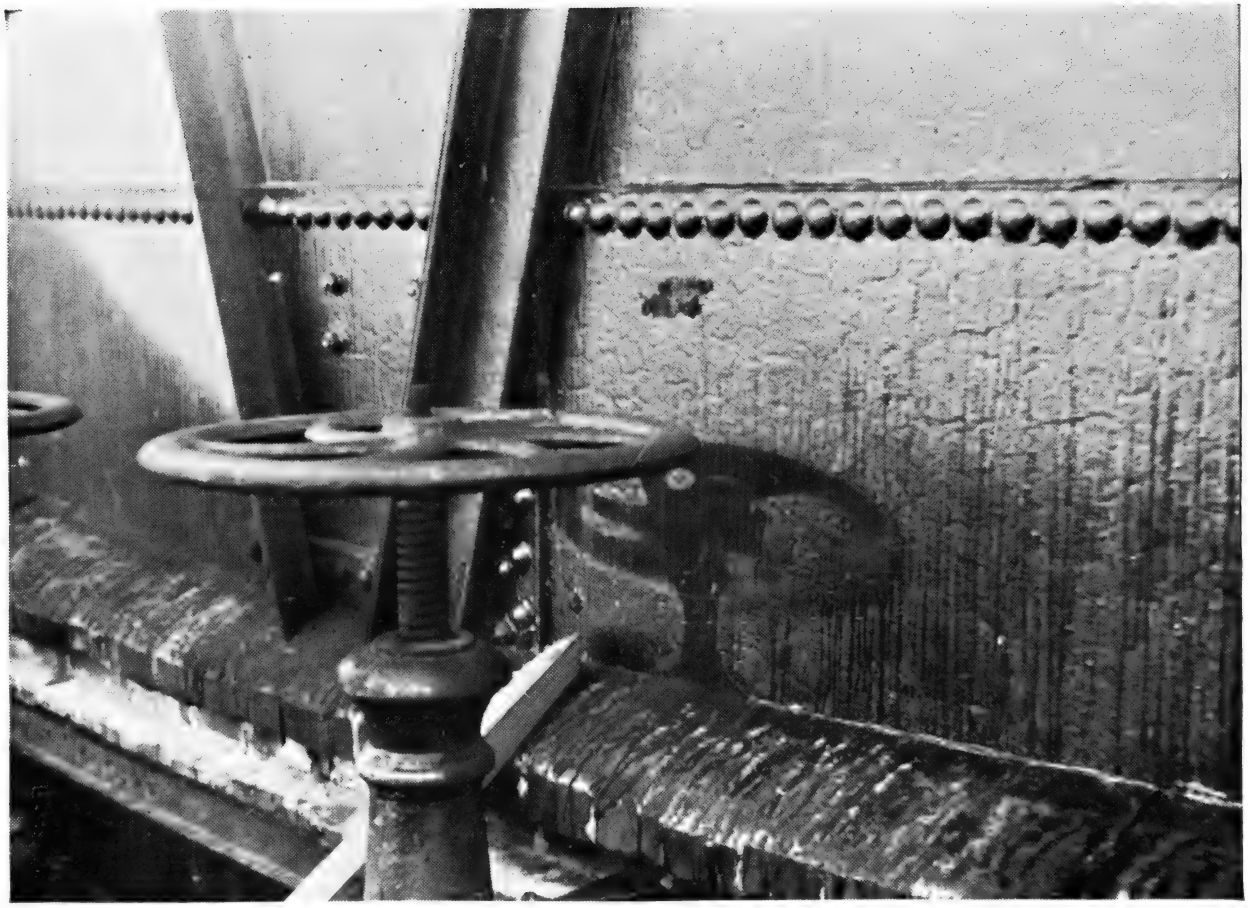

Photo No. 23. HIROSHIMA. Shadow cast by valve-wheel on side of gasholder 1¼ miles from the centre of damage. The bituminous coating on the steel plates was affected by heat radiation except where shielded by the wheel and spindle. See paragraph 53.

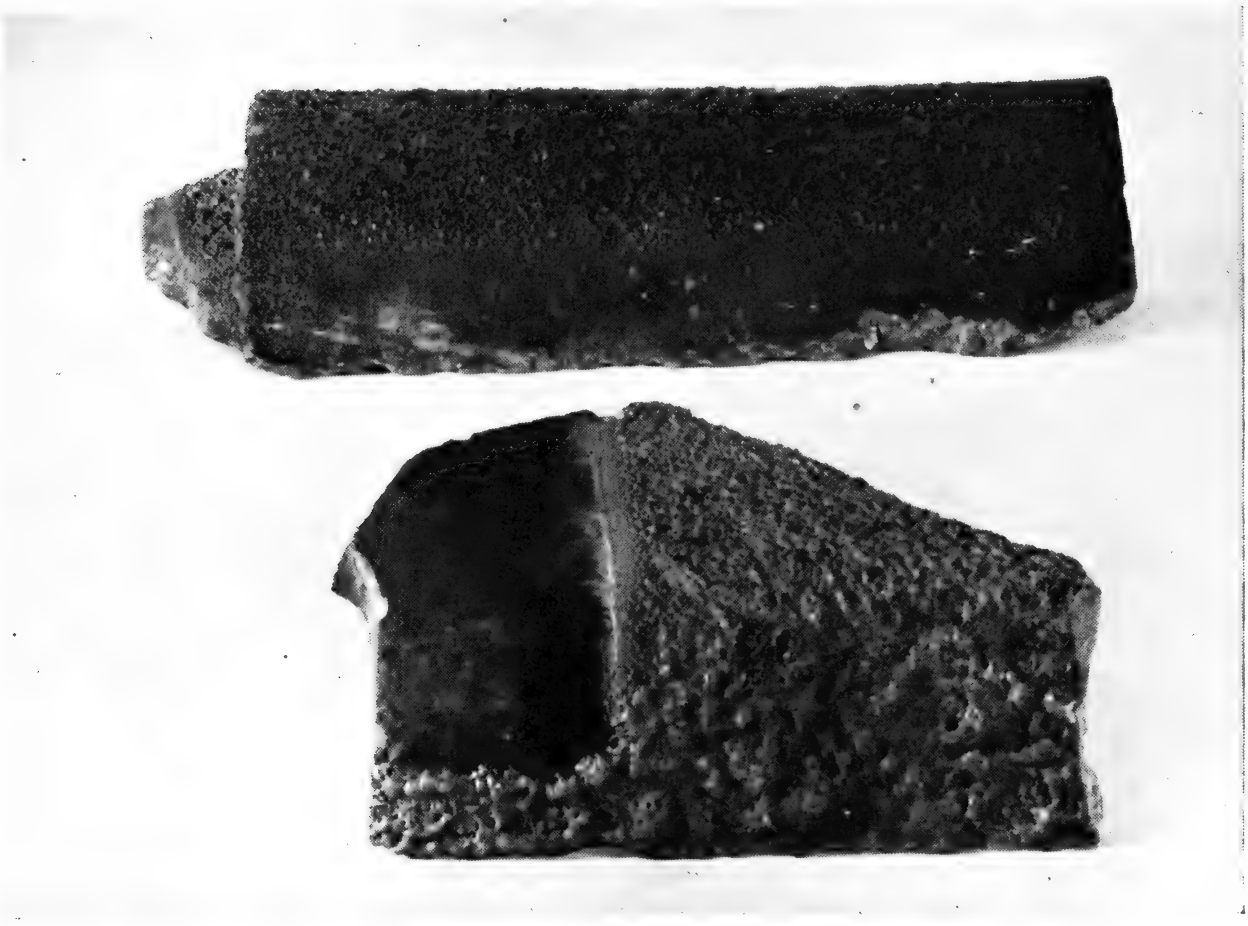

Photo No. 24. NAGASAKI. Section of ridge tile and part of pantile recovered from the centre of damage, showing the " bubbling " effect produced by the intense heat radiation. Note the gradations on the half round tile ; also the unscorched section of the pantile where the tile has been protected by the overlap of the adjacent tile. See paragraph 50.

60. Buildings and walls gave complete protection from flashburn. For example, of the men in the prison grounds of Hiroshima, roughly 1¼ miles from the centre of damage, all suffered burns except those in or screened by buildings. Of a group of 580 workers marching across a bridge in Hiroshima, nearly 1½ miles from the centre of damage, all were burnt except three at the rear of the column, whom subsequent investigation showed to have been screened by the eaves of a building. There were some very severe burns in this group, and nine deaths.

61. The Japanese reported that crops and other vegetation above ground had been completely burnt at 1,000 yards from the centre of damage in Nagasaki. In Hiroshima, some trees had been fired, apparently by flashburn, at greater distances ; flashburn marks on trees in Nagasaki extended to 1½ miles. It was noticeable in both cities that where trees which had been stripped of foliage were putting out new leaves, the fresh shoots sprang not from the branches but from the trunk.

THE PROBLEM OF FIRE

62. Attention has been drawn to the great extent of fire damage in both cities ; and that fire was not confined to wooden Japanese houses, but raged fiercely in many concrete buildings, in some machine shops, and in other buildings not normally subject to fire. The Mission therefore attached importance to the determination of the causes of fire, particularly in industrial, commercial, and public buildings, in order to assess the risk of fire in similar conditions in western cities. The aim was to determine the relative importance of two possible direct causes of fire—heat radiation, and convection by heated air ; and two indirect causes—damaged appliances, and the spread of fire from adjacent buildings.

63. The evidence presented throughout this chapter, particularly in paragraphs 52, 57 and 61, and similar evidence, leaves little doubt that heat radiation is a cause of fires in unscreened buildings, probably up to distances of 1 mile from the centre of damage. The Mission was most impressed by the accumulation of indirect evidence from the many reinforced concrete buildings the basements, the stairs, or some floors of which had been screened and contained no fire, when floors of the same buildings with windows exposed to the flash were gutted by fire. A number of reinforced concrete buildings in Hiroshima with shuttered windows escaped fire, apparently because the heat radiation, travelling at the speed of light, had arrived and died away before the blast, travelling only at a few thousand feet per second, blew out the shutters to expose the interior. The dense surrounding fires did not spread to these buildings.

64. No evidence could be found of direct fires caused by convected heat alone, that is, by heat transmitted by the air. It is difficult to think how this cause could have been isolated, or that it can be important in the presence of such intense radiated heat.

65. Indirect causes undoubtedly produced many fires. Braziers, widely used in industry as well as in the home, must have started some; some will have begun at gas leaks; and the primitive electric wiring no doubt started others, however rapid was the circuit-breaking system. It was not important to press this part of the enquiry, since experience has shown that the danger of indirect fires always exists in large-scale bombing, in every part of the world.

66. It is certain that firespread did occur in both cities; but more striking is the evidence for vast numbers of separate points of fire, which made fire-fighting among these combustible buildings hopeless from the outset. In incombustible buildings, particularly in the industrial buildings of Nagasaki, the incidence of fire in neighbouring bays was markedly erratic, and fires had not spread.

67. In summary, both direct and indirect fires must be regarded as active dangers from atomic bombs. Indeed, whether radiated heat is or is not an important cause of fire, the high temperatures produced by it plainly create conditions exceptionally favourable to the emergence and continuance of serious fires, however caused. For example, the debris of demolished Japanese houses beyond the fire zone which was examined in Hiroshima would rarely have supported fire at ordinary temperatures. Yet it must have been debris in this state which burnt there for days, presumably as a result of the initial drying and scorching by the bomb.

68. Combustible materials in fire-resistant buildings and heavy timber sections in others were burnt with unusual completeness. This is evidence of the long duration of fires even of medium intensity, which were allowed to burn virtually unchecked. It must be appreciated that the conditions of disorganization and the multitude of individual incidents created by the atomic bomb will throw an unequalled strain on any fire services. In addition, the Japanese had provided fuel for the fires by introducing a mass of wooden detail into otherwise fireproof buildings. Photograph 20 shows the interior of one of the reinforced concrete buildings of the hospital in Nagasaki, ½ mile from the centre of damage. Having resisted the blast, these buildings and their services were denied to the city at a critical time because they were filled with such material as that shown in the photograph: a false lath and plaster ceiling hung on heavy timbers, a wooden floor raised on wooden beams, and plaster walls on battens and laths. As a result, about half the occupants were killed or were trapped and died in the fires which broke out nearly everywhere among this material. It is a very plain lesson that a fireproof building should not be converted into a major fire risk and a trap for its tenants by ill-chosen fittings.

Chapter VI

RADIO-ACTIVE EFFECTS

69. The process of atomic fission gives rise to radio-activity in three ways :

First is the release of penetrating particles (neutrons) and radiation, which are directly harmful to human beings.

Second are the new products into which fission breaks the constituent material, either Uranium 235 or Plutonium 239. These fission products are themselves radio-active.

Third are materials which, penetrated by the released neutrons, become radio-active in their turn.

70. Of these effects, as they were produced by the bombs on Hiroshima and Nagasaki, those due to the action of neutrons, either directly or indirectly, were probably the least important. Neutrons did affect human beings, for

Japanese scientists found induced radio-activity in the phosphorus of their bones ; but the scale of the effect does not appear to have been comparable with that produced by penetrating radiation. Similarly, such radio-activity as was detected in the ground was probably in the main not induced by neutrons.

71. At the time of the visit of the Mission, three months after the bombing, there were areas which remained radio-active both in Hiroshima and in Nagasaki. But the amount of radio-activity was trivial then, and had been so soon after the bomb exploded. For example, cases are known of people in both cities who worked near the centre of damage from the afternoon of the bombing without ill effect. And in spite of stories to the contrary, plant life was flourishing in both cities. Thus residual radio-activity is not a danger from these bombs exploded at such heights. The small amounts of radio-activity which remained in both cities were the result of the fall of a small fraction of the radio-active fission products. In fact, the radio-active areas in each city lie downwind from the explosion ; and Japanese physicists had identified three known fission products in deposits in Hiroshima. It was foreseen that, from bombs exploded at these heights, the amount of fission products which would fall on the cities would be insignificant. From bombs burst at lower heights, however, the ground, and particularly rough ground, would receive markedly greater amounts of these products, in quantities which might leave it dangerously radio-active for days or longer.

72. The most important radio-active action at Hiroshima and Nagasaki appears to have been that from penetrating radiation. The exact make-up of this is unknown, and for convenience all this radiation will be summarily called gamma rays. Its effect is to cause injuries which, so far as can yet be judged, are analogous to but more severe than those caused by over-exposure to X-rays. For the description of these effects, and the bulk of kindred material in this report, the Mission is indebted to the Medical Section of the Joint Commission for the Investigation of the Effects of the Atomic Bomb, which will ultimately publish a more detailed and more accurate report than this interim statement.

73. The gamma rays were very penetrating, and passed through the skin without affecting it. As a result, those exposed to gamma rays, if they were protected from flashburn and from indirect injury, showed no immediate ill-effect. Even those severely irradiated probably did not show the characteristic symptoms, nausea, vomiting and fever, for 24 hours, and rarely died in less than one week. These first symptoms were followed by bloody diarrhoea, occurring most frequently in the second week, at which time loss of appetite and general malaise also became marked. Patients began to lose their hair after the first week.

74. Thereafter, in the severe cases, the clinical picture came to be dominated by signs of deficient blood formation. This effect on the blood is indirect, and therefore delayed : the gamma rays do not attack the cells in the blood-stream, but the primitive cells in the bone marrow, from which most of the different types of cells in the blood are formed. Therefore serious effects begin to appear only as the fully-formed cells already in the blood die off gradually and naturally, and are not replaced as they would be normally by new cells formed in the bone marrow. In severe cases, it was apparent that the gamma rays had virtually killed the entire bone marrow. In such cases, all three types of cells formed in the marrow became deficient : red cells, platelets, and white cells (granulocytes). As red cell formation ceased, the patient began to suffer from progressive anaemia. As platelet formation ceased,

the thin blood seeped in small and large haemorrhages into the skin and the retina of the eye, and sometimes into the intestines and the kidneys. The fall in the number of white cells, which was useful in diagnosing mild cases because it could be detected by taking blood counts, in severe cases lowered resistance, so that the patient inevitably fell prey to some infection, usually spreading from the mouth and accompanied by gangrene of the lips, the tongue, and sometimes the throat. Death in these cases was the result of a combination of anaemia, internal bleeding, and infection. Deaths probably began in about a week after the explosion, reached a peak in about three weeks, and had for the most part ceased after six to eight weeks.

75. The distances at which these effects were felt are not easy to determine. It is thought that gamma rays ultimately caused the death of nearly everyone who was fully exposed to them up to a distance of $\frac{1}{2}$ mile from the centre of damage. A figure can be obtained for the 50 per cent. chance of survival, from the evidence of two groups of workers who had been brought into Hiroshima from an outlying village, and who were working in the open but screened by wooden buildings at 1,200 yards from the centre of damage. Of the total of 198 men, 6 were killed immediately by debris and 95 of the survivors subsequently died, it is believed all from the effects of gamma rays. Allowing for some small protection afforded by the wooden buildings, it is estimated that people in the open have a 50 per cent. chance of surviving the effects of gamma rays at $\frac{3}{4}$ mile from the centre of damage. As regards lesser effects, loss of hair was recorded up to $1\frac{1}{4}$ miles from the centre of damage, and some doctors felt that the milder forms of radiation sickness, more difficult to diagnose, may have extended to 2 miles.

76. The gamma rays are capable of penetrating considerable thicknesses of building and other material. They thereby pose new problems of protection, the scope of which is not yet fully understood, and is best illustrated by examples.

An unusually strong three-storey reinforced concrete building at Hiroshima, less than 250 yards from the centre of damage, contained 23 people whose fate can be traced. The building remained structurally undamaged, and none of these people was killed immediately ; nearly all had some lesser injuries from debris and fire, but were able to walk to hospital for treatment. Subsequently, between the sixth and the seventeenth day after the explosion, 21 of these people died, probably all from the effects of gamma rays. The two survivors were in the telephone room on the ground floor, where they were shielded by all the floors and possibly by adjacent buildings.

In a five-storey reinforced concrete building 700 yards from the centre of damage, gamma rays caused many deaths on the fourth and fifth floors and a few on the third, but killed no one below this who was screened by all the higher floors.

A partly underground concrete shelter less than $\frac{1}{2}$ mile from the centre of damage had no gamma ray casualties, or indeed any but minor debris injuries.

At distances approaching 1 mile from the centre of damage, less massive buildings began to protect from gamma rays. For example in the City Hall of Hiroshima, at this distance, there were no deaths from gamma rays and at most 6 mild cases of radiation sickness.

Only tentative conclusions can yet be drawn from this and similar information.

77. The effects of gamma rays on human reproduction necessarily form a long-term study, which will continue for some years. Of the effects already detected, the most striking are those on pregnancies at all stages from two months onwards. At distances up to 1,000 yards from the centre of damage, pregnant women who survived have had miscarriages. At distances up to $1\frac{1}{4}$ miles from the centre of damage, pregnant women who survived have had either miscarriages or premature infants who died very soon. Even beyond this range, up to nearly 2 miles, only about one-third of pregnant women have given birth to what appear to be normal children. Two months after the explosion miscarriages, abortions, and premature births throughout Hiroshima were nearly five times as frequent as in normal times, and formed more than one quarter of all deliveries.

78. Sperm counts made in Hiroshima show that a high proportion of men exposed to gamma rays, up to perhaps $\frac{3}{4}$ mile from the centre of damage, have reduced powers of reproduction. Gamma rays also stopped menstruation in women ; but this condition was so common throughout Japan, it is thought as a result of war-time diet and overwork, that no conclusions regarding its permanence can yet be drawn.

Chapter VII

CASUALTIES

79. The important causes of direct injury from the explosion, flashburn and gamma rays, have been described in the two preceding chapters. However, with the atomic as with other bombs, indirect injuries caused the death of a high proportion of the casualties, and probably of the bulk of them—except in so far as these were killed as it were several times over, by each lethal agent separately.

80. The greatest number of indirect injuries, and indeed of all deaths, appears to have been caused by the collapse of buildings. Photograph 19 shows the Japanese house as a light building, but it is not therefore to be despised as a lethal weapon, for its heavy roof timbers and tiling are inadequately supported (see paragraph 37) and must have killed or trapped thousands. Photograph 20 shows that injuries of the same kind were caused in the stronger buildings by the mass of wooden detail with which the Japanese embellished them, and which has been described in paragraph 68. Mechanical injuries resulting from people being thrown about, or from having arms or legs violently removed by flying debris, appear to have formed a lower proportion than in conventional attacks.

81. Fire in conventional air attack is rarely a major cause of casualties. There have been exceptions, among them the great incendiary raids on Hamburg and Tokyo, where the number of dead approached that in Hiroshima; but drawn from a much larger damage area. Very many people were, however, burnt to death in Hiroshima and Nagasaki, for there was almost no attempt to rescue those who were trapped or hemmed in by debris while points of fire sprang up round them. Burns received in the fires appear throughout the records of those admitted to hospital.

82. In Nagasaki but not in Hiroshima, a rumour was current which age has made almost respectable, for it appeared in the London Blitz and before that in Barcelona during the Spanish Civil War. This was that large numbers of people had been ripped open by the blast, and their entrails exposed; their eyes

and tongues were said also to have hung out. Experience in this country has shown that blast pressure alone does not in fact cause these sensational effects on the human body. It was therefore not unexpected that two Nagasaki survivors who had spoken of seeing hundreds or thousands of such bodies on examination reduced their claim to one or two. Flying debris would be expected to produce a few such injuries. Cases of genuine injury from high blast pressures, such as ruptured ear-drums, were rare among survivors.

83. No conclusions can yet be reached regarding the relative importance of the different lethal agents. It is thought that those who died immediately were divided roughly equally between those killed by debris and those burnt, either by heat radiation or in the fires. Severe injuries from debris may extend to 2 miles, but are rare beyond $1\frac{1}{4}$ miles from the centre of damage. Beyond this distance gamma ray effects fall even more rapidly, and the major source of casualties is flashburn and fire.

84. Disasters as vast as those which befell Hiroshima and Nagasaki are difficult to fix in numbers. Most of the city records were destroyed, many public servants were killed, and in the chaos which followed little note was taken of the fate of individuals when the population was in mass flight. The Mission had to content itself with estimating from such records as were available that the number of people killed in Hiroshima lay between 70,000 and 90,000. Since then the Occupying Authority have published official figures for Hiroshima, of 78,150 dead, as well as 13,983 still missing. For comparison, the number of those killed by air attack during the whole war in London was 30,000, and the number of those killed throughout Great Britain, including London, was 60,000.

85. The number of those killed by a bomb depends on the number and whereabouts of those exposed to it. Therefore the number of dead is only a crude measure of the effects of the atomic bomb ; a better measure is given by the percentages of those at various distances from the explosion who died. It was possible to estimate these from comparatively good records which exist of the whereabouts in Hiroshima and of the subsequent fate of about 15,000 school-children. Few of these were actually in school when the bomb fell, for most were scattered through the city in groups doing a variety of war jobs ; so that it is believed that they form a representative sample of people going about their normal work in the city, some in the open, others in buildings giving varying protection. The Mission's interpretation of the records of the fate of these children is as follows :—

Distance from the centre of damage	*Percentage of those within this zone who were killed*
0–$\frac{1}{4}$ mile	95 per cent.
$\frac{1}{4}$–$\frac{1}{2}$ mile	85 per cent.
$\frac{1}{2}$–$\frac{3}{4}$ mile	58 per cent.
$\frac{3}{4}$–1 mile	35 per cent.
1–$1\frac{1}{2}$ miles	13 per cent.
$1\frac{1}{2}$–2 miles	$\frac{1}{2}$ per cent.

Experience in Great Britain has shown that in conventional raids children of school age are neither appreciably more nor appreciably less vulnerable to bombing than are adults. It is therefore reasonable to apply this table equally to adults.

86. It was possible to obtain the distribution of population in Nagasaki, where those in the Urakami valley exposed to the explosion numbered rather less than 100,000. On applying the table to this distribution, the resulting figure of dead is 37,000. This may be regarded as reasonable confirmation of the table ; for it is in fair agreement on the one hand with the estimate of 34,000 dead made by the Mission from Japanese population records, and on the other hand with the figure of 40,000 killed which is current among medical authorities. No official figures for Nagasaki have yet been published by the Occupying Authorities.

87. As the difference between the figures for Hiroshima and Nagasaki shows, the number of those killed depends rather obviously upon the number of those who were present. It is therefore customary in considering the effects of bombs to use a casualty rate from which inequalities in the distribution of population have been removed. For this purpose a standard density of population is assumed at about 45 to the acre, the density in the central London boroughs and the larger British cities. At this density the average effect of the Hiroshima and Nagasaki bombs is 65,000 killed. In British cities, the better protection afforded by the houses, their lower susceptibility to fire, and improved rescue services, would reduce this figure by an amount which can only be conjectured, but which is unlikely to exceed one-quarter. (This is equivalent to reducing all distances listed in the table by one-eighth.) The standard figure in British conditions would therefore be approximately 50,000 dead. The comparable standard figure for the German V2 rocket was about 15 dead.

88. The figure of 50,000 dead from one atomic bomb in average British urban conditions is probably the most important which this report contains. It shows that much the most serious effect of the atomic bomb is in producing casualties. The problem of providing against and of treating gamma ray casualties in particular is exceptionally grave and difficult.

Conclusions

89. Consider a British urban area with an overall housing density of about 15 per acre (including open spaces), and a population density of about 45 per acre: and apply to it the radii of damage listed in paragraph 38. The explosion of a single atomic bomb of the power and at the height of those in Hiroshima and Nagasaki would demolish or damage beyond repair approximately 30,000 houses. The number of houses requiring extensive repair would be approximately 35,000; the number temporarily uninhabitable and requiring first-aid repairs would be between 50,000 and 100,000. Thus a total of roughly 400,000 people might be rendered temporarily homeless, of whom about one-half could return to their houses after lesser repairs. Not all the remaining 200,000 would constitute a rehousing problem: because about 50,000 of them would be dead or would die within eight weeks, and a comparable number would require extended hospital treatment. Therefore the number of non-casualties to be rehoused, either permanently or for the months required to carry out major repairs, would be approximately 100,000.

90. This picture somewhat over-estimates the average effect; for example, in the nature of things, cities of less than 400,000 inhabitants could hardly have so many homeless. In fact, few British urban areas are as dense as this throughout a circle of 4 to 5 miles diameter, such as the application of paragraph 38

presupposes. Nevertheless, the figures make vivid the scale of the disaster; and will be appropriate to an incident in the larger British and other western cities.

91. As paragraphs 29-35 show, the distances at which factory buildings would be affected are roughly comparable, and the scale of the immediate industrial loss would therefore be of the same order. The final industrial loss, however, would be considerably lower if fire precautions were adequate and if machines were not left to weather.

92. It has long been known from the experience of raiding on Great Britain that reinforced concrete and steel framed buildings are much more resistant to blast than are buildings of the normal British and Continental design, having load-bearing walls. The observations at Hiroshima and Nagasaki reported in paragraphs 24-28 fully confirm this. Casualties in framed buildings are usually the result of structural collapse, falling ceilings and partitions, and flying debris and glass. These risks remain, and to them are added the risk from flashburn, from fire (see paragraph 68), and from gamma rays. Framed buildings in which these risks have been minimized should be advocated for all public and semi-public buildings.

93. The conditions of the explosions in Hiroshima and Nagasaki could be changed in a number of ways. One way is, that the height of burst could be lowered. This would probably reduce the area of damage, but damage to massive buildings and to bridges near the centre would become more severe, and from sufficiently low bursts would extend to underground services. The increase in casualties near the centre, particularly from gamma rays, would be expected to be offset by the decrease in more distant casualties. A serious effect, however, would be created by the greater density of fission products on the ground which would result from a lower explosion, for these would make the area dangerously radio-active for a period of days.

94. The overall picture, then, is sombre. Even ignoring changes in attack and in the development of the bomb, the damage figures given, say, in paragraph 89, are very serious. And these figures are a measure only of the blast effect of the bomb. With them must be kept in mind the grave problem of fire, direct and indirect, which the bomb has created, which has been discussed in paragraphs 62-68. Both are overshadowed by the scale of casualties produced by the bomb, which make the mere disposal of the dead a major problem. The figures given in Chapter VII speak for themselves.

THE MORE IMPORTANT EFFECTS OF ATOMIC BOMBS ON PEOPLE AND THEIR HOMES

Explosion as at Hiroshima and Nagasaki