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29 January 1946

SUBJECT: Receipt for Secret Document.

TO : Brigadier General Grandison Gardner, USA, Deputy to the Chairman, U.S. Strategic Bombing Survey, AAF Annex #1 Gravelly Pt., Washington, 25, D.C.

1. Receipt is hereby acknowledged of one (1) copy of "Report of the British Mission to Japan on an Investigation of the Effects of the Atomic Bomb Dropped at Hiroshima and Nagasaki", Copy #3.

FOR GENERAL GROVES

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REPORT

OF THE

BRITISH MISSION TO JAPAN

ON

AN INVESTIGATION OF THE EFFECTS OF THE ATOMIC BOMBS DROPPED AT HIROSHIMA AND NAGASAKI.

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F O R E W O R D

The party which was sent to Japan, by the British Chiefs of Staff, comprised representatives of the Civil Defence Department of the Home Office and of Service Ministries. It included also a representative of the Government of India. The list of personnel is given below.

The initial arrangements for the trip were made by the British Bombing Survey Unit; the arrangements overseas were made by the United States Strategic Bombing Survey Unit, and to each, keen appreciation is expressed for all the provisions made by them.

The accompanying Report covers the work of the Home Office Team, but the Service and India Representatives were interested in the same subjects and cooperated freely and effectively. They will report independently upon topics of special interest to their respective Services.

The British teams, the USSBS, Physical Damage and other teams, again cooperated freely and the results obtained by each mission are being made available to the other. Much information has already been exchanged and grateful thanks are due to U. S. S. B. S. for their unstinted help and cooperation.

The bulk of the information on casualties, which is included in the Report, was placed at the disposal of the British Mission by the Medical Section of the Joint Commission for the Investigation of the Effects of the Atomic Bomb, under Colonel Oughterson, to whom and to whose team the mission is greatly indebted. The material was the special charge of one of the Service representatives - Colonel O. M. Solandt to whom in turn best thanks are accorded.

The British Report of the Home Office team is in the nature of a preliminary or interim report. The U.S.S.B.S. will be issuing a much fuller and more comprehensive report, when the mass of data they have accumulated has been analysed, and reference should be made to this, for their more considered views and opinions.

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S U M M A R Y

The Report is based on the survey made by the British team of the damage caused by the atomic bombs which were dropped on the Japanese cities of Hiroshima and Nagasaki. It is of a preliminary character and a fuller report will later be available, prepared by the United States Strategic Bombing Survey, with whose teams the British team cooperated.

Descriptions are given of the type and extent of the material damage in each of the two cities.

Fire was the cause of much of the destruction, and there is evidence that some of the fires were initiated by primary and others by secondary agencies. Radii of damage were estimated for Japanese dwellings and for other buildings - e.g., reinforced concrete and steel-framed structures, buildings with load-bearing walls, etc. as detailed in the Table of Contents. The effects of heat radiation and also of nuclear radiation, were investigated and are described. Both effects are serious and differentiate between the action of the atomic bomb and ordinary HE weapons.

Section 6 of the Report deals with Conclusions and Applications, and there estimated have been made of what might be expected in Europe and in Britain from atomic bombs detonated under similar and under different conditions, and from possible penetrating bombs.

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REPORT

OF THE

BRITISH MISSION TO JAPAN ON

AN INVESTIGATION OF THE EFFECTS OF THE ATOMIC BOMBS DROPPED AT HIROSHIMA AND NAGASAKI -

1. INTRODUCTION

1.1 OBJECT AND SCOPE OF THE INVESTIGATION - The object and scope of the scientific mission to Japan were laid down in directives signed on behalf of the Chiefs of Staff by Air Vice Marshal Williams, Assistant Chief of the Air Staff (Operations), that to the Home Office party being also countersighed by Sir Reginald Stradling, Chief Advisor to the Research and Experiments Department, on behalf of the Civil Defence Department of the Home Office. The object of the mission was to study the effects of bombing in Japan, and specifically of the two atomic bombs at Hiroshima and Nagasaki. The scope of the mission was confined to these effects; the directives instructed it not to enquire into research, constructional or operational aspects of atomic bombing. The brief attached to the directive underlined ultimately the aim of the mission was less to list the damage which it found in Japan than to draw lessons from what was found which would be applicable to European targets and, in particular, to Civil Defence in Great Britain. We quote the introductory sentences from the brief:-

On the structural side, the fundamental aim is to estimate the resistance to atomic bombs of the various types of housing and other construction which might be employed in Britain now or in the future. On the medical side, it is to obtain the distribution and types of casualties, in particular as a guide to shelter and rescue policy.

This report, while describing what was found at Hiroshima and Nagasaki, is accordingly directed in the main to the provision of information which will be useful in predicting what would be the effects of similar bombs in Europe and specifically in Great Britain.

1.2 LIMITATIONS OF METHOD - In Section 2 below, details are given of the differences between Hiroshima and Nagasaki as physical targets, and between the circumstances under which the incidents there took place. These differences in themselves make it diffecult to give a unified picture which can be labelled "This is what an atomic bomb does". In addition, in the nature of things, the transferance of experience between a target so unfamiliar to the mission as the Japanese, and one so different in many respects as the British, could not be made with precision. Figures which appear in this report must therefore be treated as representing the scale and order of the phenomena without claiming final accuracy. They may need to be modified later, when the mass of data accumulated by the United States Strategic Bombing Survey (USSBS) has been analysed, and their Final Report has become available. It is not thought that these modifications are likely to be very significant.

For the same reason, we have underlined the qualitative aspects of the damage. The atomic bomb produces a number of effects so different from those of ordinary bombs, either in degree of in kind, that their description and assessment is in many ways more fundamental than are detailed estimates of familiar effects. Moreover, these new effects will remain important in the future, when the size and character of the bomb may have changed so much that numerical estimates made now will have ceased to be applicable. For these reasons, our stress has been on the kind of effects to be expected, and the scale on which they must be expected.

1.3 PREDICTIONS - These limitations being understood, we have nevertheless made estimates of what may be expected in Europe and in Britain, from atomic bombs (for example, penetrating bombs). (See Section 6) -

The present Report which is a summary and interim document, is condensed from interim reports drawn up by the individual field workers who composed the mission. More detailed reports will be drawn up by these specialists in the near future, each on his own field, and will be available through Sir Reginald Stradling. Somewhat later, as already mentioned, there will also be available the full reports of the surveys conducted by United States Strategic Bombing Survey at Hiroshima and Nagasaki and elsewhere in Japan.

2. THE TWO TARGETS

2.1 DIFFERENCES IN ATTACK - The differences in response at Hiroshima and Nagasaki, which impose some of the limitations set out in section 1.2 above, have two causes: differences in attack, and differences in the targets themselves. Differences in the targets are described in sections 2.2 and 2.3 below. Differences in attack were of two kinds:

2.1.1 Differences Between the Two Bombs - The mission did not seek information on this subject, which the directive excluded from its scope. A good deal of information, however, is contained inthe various official statements which have been made public from time to time, or can readily be deduced from them. In addition, other information, of varying degrees of unreliability, was volunteered to us as common knowledge. It will suffice to state that the bombs at Hiroshima and Nagasaki were of different designs, the explosive content of the former being Uranium 235 and of the latter plutonium 239. Differences in effectiveness might, therefore, be expected, and were in fact found, as the survey results indicate, though the two bombs apparently did not differ greatly in their general effects.

2.1.2 Difference in Position and Height of Burst - Both bombs were air burst. The direction of the burst can be estimated from unscorched "shadows" which were cast by intervening objects on surfaces subject to scorching, in the manner described in section 4.2 below. Anumber of such observations then fix the point on the ground vertically below the burst. This point having been determined, the same method serves to estimate the height of burst. (Compare Photographs Nos. 17 and 18). In both cases, but particularly in determining the height of burst, care must be taken to make some allwoance for the size of the fire ball, as explained in 4.2. It proved desirable to use shadows cast by fairly narrow objects with parallel sides, in order to thake a mean of readings from the two sides of the shadow.

For each city, the point of burst will hereafter be called the air-zero, abbreviated A.Z. The point on the ground vertically below this will be called the ground-zero, abbreviated G.Z. At both cities, both points, but particularly G.Z., had been determined first by the Japanese, then by

U.S.S.B.S., and by others. No attempt was made, with the instruments at our disposal, to make detailed fresh determination. Enough measurements, however, were taken in each place to confirm the general location of G.Z. as that marked as the centre of the circles on the accompanying maps; and to give reasonable estimates of the height of burst. These are:

Hiroshima - Just below 2000 ft.

Nagasaki - Approximately 1750 ft.

These are the distances between G.Z. and A.X. Since G.Z. was effectively at sea level at both places, they may be taken as heights of burst above sea level. Differences in the position of G.Z. relative to the main built-up area in Hiroshima and Nagasaki are remarked under 2.2. and 2.3 below.

2.2 HIROSHIMA - is a city built on the islands and shores of the delta where the river Otagawa falls into the Inland Sea. Although there are hills rising to 700 ft. and 800 ft. tb the immediate northwest and northeast, the city itself stretches over flat ground in all directions for roughly two miles from its centre: the built-up area was approximately 13 square miles. Of this total, pre-raid cover suggests that over 20% was devoted to some kind of industrial or business enterprise, including extensive military storage and shipping facilities. The major industrial plants are modern and distributed peripherally along the southern and western outskirts of the city at distances of between 1 1/2 and 2 miles from the centre. The city also contained a considerable number of reinforced concrete buildings owned by banks, insurance companies, department stores, newspapers and similar mercantile enterprises.

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So far as can now be judged, the centre of the city was spaciously planned, having some fine streets and temples. It is clear that the city was a pwosperous trading centre, with some contacts with the outside world. A number of Japanese whom we met had soent some time either in the United States or in Hawaii.

Before the war, Hiroshima, like most Japanese cities, was growing; its census population in 1930 was 270,000 and in 1940 was 345,000 at which figure it remained until 1944. Thereafter there was a decline in population; at the beginning of 1945, when the population was approximately 320,000, it seems to have been falling at the rate of about 2000 per month. The catastrophic incendiary raids on Tokyo and other great Japanese cities in the second week of March, 1945, had an immediate effect; the population fell to 285,000, and by April it was below 260,000. These estimates were made for us by the Census Officer, and do not continue beyond this date; but the rationing authorities estimated the population in July to have been 245,000.

These figures are probably what Japanese call the "registered" population, for example, for such purposes as rationing. This is normally thought to be about 80% of the actual population, which may, therefore, have totalled say 306,000. In addition, there were roughly 10,000 troops stationed at Hiroshima, and perhaps 4000 workers had been brought in to cut fire breaks. Thus a reasonable estimate of the population at the time of the raid may be as high as 320,000.

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The large fall in population in the Spring was the result of evacuation, in the main compulsory, accompanied by the systematic destruction of evacuated houses to form fire breaks. This program was only partially completed when the atomic bomb fell at about 8:10 a.m. on the 6th of August, 1945.

G.Z. lies at approximately 1000 feet from the conspicuous T-shaped bridge, which rumour has it, was the aiming point. Eyewitnesses are agreed that they saw a blinding white flash, felt a rush of air and heard a loud rumble of noise, followed by the sound of rending and falling buildings; all also speak of the settling darkness caused by a universal cloud of dust. Shortly afterwards, they became aware of fires in many parts of the city.

Falling as it did in the centre of a city, the greater part of which consisted of an unbroken expanse of flimsy wooden houses, the bomb spread its destruction with great uniformity. Directly of indirectly, it appears to have initiated innumerable fires which burned vertually unchecked for some days, and gutted about four square miles. Like other defence services, the fire service was overwhelmed. There are contradictory accounts of whether it did or did not attempt to fight fires in the first twelve hours, but no civilian defense services in the world could have met a disaster on this scale. On August 6, the authorities at Hiroshima were making preparations to meet what they believed to be a threatened incendiare raid: they were not prepared for a holocaust.

As Photograph No. 1 shows, the appearance of Hiroshima today is that of a burnt city. The traveller who comes to it from Tokyo sees the same flat stretches where wooden buildings have burnt to the very ground, punctuated by a few shacks newly built from salvaged iron sheeting, by chimney stacks which mark the site of burnt out public baths, and by concrete buildings which have survived the fire. True, the concrete buildings at Tokyo are usually sound inside, whereas closer inspection shows similar buildings at Hiroshima to have had extensive internal fires. But there are Japanese cities which have been gutted by incendiary bombs, among them Kobe and Osaka, where equally the fires have burnt out the inside of most of the concrete buildings. After the initial flight of population, there has recently been a considerable return; the present census population (November, 1945) is 138,000.

2.3 NAGASAKI - is a city on the southerly Japanese island of Kyushu. It has a long natural harbour; the western shore is occupied mainly by ship building and repair, the eastern shore by smaller yards, wharves, and houses, The main commercial area of the town lies near the head of the bay on its east shore. Here a small valley runs northeast, filled by crowded and noticeably dirty Japanese houses. Meanwhile, the main industrial area of Nagasaki, with its attendant jostle of workers' houses, stretches north and south along the river Urakami. Each of these developments is encompassed and compressed by the spectacular mountains which surround the bay and rise steeply to over 1000 ft. on all sides; and in fact many buildings stood high above the valleys. The built-up area was approximately four square miles, of which about 15% was industrial. It is clear, however, that these industries dominated Nagasaki, where everything that survives bears the stamp of a vast industrial slum. The industry, mainly shipbuilding and armament, was owned almost entirely by the firm of Mitsubishi. Latterly, it had outgrown the many acres of framed sheds which can be seen on the map, and was being dispersed among local schools and other large buildings, as well as some tunnels.

Nagasaki has few imposing buildings, and these are mostly schools built in reinforced concrete. An exception should be made of the hospital buildings, which, with the medical school adjacent to them, form a complex of which any European city of similar size might be proud. In fact, the standard of treatment at the hospital appears to have been low; nevertheless, the severity of the disaster was increased by the fires which made these bu ildings useless.

Nagasaki had at one time been a naval base, and earlier a winter port for the Russian fleet. Since the opening of Sasebo Naval Base, its importance had declined; and probably its wartime production of torpedos had given local industry a useful fillip. Its census population in 1930 was 218,000 and in 1940 was 253, 000; in the interval, four outlying districts had been incorporated. The 1944 military census gave a population of 272,000, including army personnel. The registered population on May 31, 1945, was 207,000. Making the usual allowance for the unregistered fraction of population, and adding a military population known to be just under 5000, the total population at the time of the bomb may be taken to have been just in excess of 260,000.

A detailed description of the raid exists in an account prepared by the Prefect on 1st September. As at Hiroshima, bombing was from about 29,000 ft.; the bomb fell just after 11:00 a.m. on 9 August in the industrial area between the two large Mitsubishi Ordnance Plants north of the bay. Again there was a bright flash, which gave place to a haze of white smoke which rapidly darkened. Witnesses speak of a roaring sound, some feeling of pressure and wind, and of heat. Since the population was aware that an atomic bomb had fallen on Hiroshima the disaster was less unexpected. Nevertheless, it overwhelmed the medical and civilian services. Owing to the smaller area of Nagasaki, the barriers formed by the surrounding mountains, and in particular the position of G.Z. in the industrial section of the city, the area of destruction was markedly smaller than at Hiroshima, being roughly 1-1/2 square miles. For this reason, the Japanese at first reported the bomb to be a smaller version of the Hiroshima model. The local population, feeling that the bomb had missed the centre of the town, took to the hills in fear of a second.

As at Hiroshima, there were extensive fires; but they spread comparatively slowly, and do not offer the compact appearance of the area of burnt out in Hiroshima. On the contrary, the impression which Nagasaki makes on the visitor is more novel and eerie. Long lines of steel framed factory sheds, nearly a mile from G. Z., lean their skeletons away from the explosion. Concrete buildings have the sides facing the blast broken in like boxes. Over a large area, such blast resistant objects as telegraph poles and tram standards are leaning away from A.Z.; on the surrounding hills, trees have been blown down to considerable distances. Thus Nagasaki presents much more the appearance of a city struck by tremendous hurricane."

* A census completed late in November, 1945, gives the population as 143,000. This is within 1% of the estimate made by the Mission from samples taken during its casualty enquiries.

* These features do not show well on panoramic photographs, and Photo No. 2 does not include them. Photographs such as No. 10 give some idea of the effects.

2.4 POINTS OF SIMILARITY AND DIFFERENCE - In summary, the main points of difference are that the bombs

were of different materials and construction,

detonated at different heights, and

in different positions relative to the main concentration of Japanese housing.

Further, the cities were markedly different

in geographical layout,

in uniformity of building, and

in the type and strength of non-domestic buildings, exposed to risk.

As a result, the response of the targets showed some marked differences. We have drawn attention to the difference in the extent and compactness of the areas of fire. Adequate explanations for this difference exist in the differences of building and building density. There are some differences in the appearance of the blast damage. At Nagasaki, a good deal of the damage resembled damage done by a high steady wind. This appearance was rare at Hiroshima, where in turn there were some appearances suggesting the operation of the negative phase of the blast wave, of which there seemed somewhat less evidence at Nagasaki. Yet these appearances may also have sprung from the differences in building types.

Moreover, the large extent of the area at risk at Hiroshima made for a much wider range of building strengths, which are not always apparent from an external view. As a result, within the uniform destruction of Japanese houses, "freak" behaviour of such structures as reinforced concrete framed buildings at unexpected distances is more common at Hiroshima. Finally, it should be remarked that Hiroshima had been struck by a typhoon at the beginning of September, and by a second early in October, which did not contribute to the ease of analysis of results there.

Against this, there is a formidable array of points of similarity, which from the burden of the sections which follow. More important than differences in the extent of fire is the high risk of fire created by the bombs. The whole phenonemon of radiation, whether of heat towards one end of the spectrum or of gamma rays towards the other, is common to all such bombs and to no others. Similarly, there were important likenesses in the effect of blast. Air burst at these considerable heights necessarily give a marked downward component of pressure over a large area, so that there was a tendency to failure of roofs in both places. The striking appearance of the trees near G.Z. in both places with their main branches town off by downward push, had the same origin. A more important point may be associated either with air bursting or with the completeness of the destruction caused by the bomb. This is the absence of any massive piece of debris carried over large distances. Small debris, such as tiles, battens, etc. was apparently thrown considerable distances, being found on the flat roofs of the tall reinforced concrete buildings, etc. Identifiable debris of any appreciable size was however always found close to its point of origin, and where massive slabs, such as bridge decking, had been shifted, the movement, through on occasion critical, was comparatively small.

3. BLAST EFFECTS

3.1 CHIEF FEATURES - The blast effects of the atomic bomb are in most respects similar in character to those of other large blast weapons, the differences being mainly scale and directional effects. The chief features are:

3.1.1 Mass Distortion - The distortion or destruction of whole buildings due to the uniformity of blast effects over them - in contrast to the local damage occasioned by small HE bombs. The mechanism of failure is seen most clearly in those buildings which, though not completely demolished, are badly distorted, and the resemblance to hurricane effects is then very striking. The distortion results from the transmission of the forces from the exposed face through the floors and/or roof members to the sheltered face of the building. The leaning over of the buildings occurs in all types, from the typical domestic structure to steel framed or reinforced concrete industrial or public buildings. Obviously, the floors and roof members which transmit the forces from the exposed to the unexposed faces, are subjected to compression, and many instances have been noted of compression failures, in these members, mainly buckling. An example is shown in Photo No. 5 where reinforced concrete roof slab of Building W, 1600 ft. from G. Z. at Nagasaki has buckled upwards.

3.1.2 Dishing of Roofs - Though some roof slabs are buckled upwards, by the compression forces as mentioned above, the more usual failure is a dishing downwards of the slab - See Photo No. 1. This is accounted for by the downward component of the blast from the explosion. Comparatively few examples of this type of failure have been experienced in Europe with H. C. bombs or mines, since air bursts have been infrequent with them. Roof slabs have been dished-in by instantaneously fuzed bombs, e.g., by the Flying Bomb, or by mines, but in such cases the main damage is more localized, the slab failing under a concentrated load and usually being perforated. Unusual other effects which result from the downward direction of the blast, particularly near G. Z., are

(a) telegraph & other poles remained vertical near G.Z., though overturned or filted back at greater distances.

(b) Trees quite near Zero, the trunks of which remain vertical, have had branches broken off apparently by vertical downward forces.

(c) Reinforced concrete and other covers to tanks, fractured.

(d) Curious example of the front step of a building at Nagasaki being broken at its junction with the main building and tilting, the front edge of the wide slab being depressed some inches. Evidently there was very poor filling under the slab and this had compressed. A wing wall to a light-area in front of the same building had likewise been depressed several inches. No evidence could be obtained of any depression of the water surface in the river, or of any wave being generated there.

3.1.3 <u>Infrequency of Suction Effects</u> - The comparative infrequency of failures which can definitely be attributed to the suction phase of the blast wave. We have not had access to test data on the atomic bomb, and are unable to state with any certainty what the duration of the positive phase might be. It appears, however, that it was sufficiently long to ensure that those structures and structural members that were weak enough to fail, failed under the positive phase: if they did not do so, they were strong enough to resist the negative phase, though this would be of longer duration. An exception was when the target was more fitted to resist the positive than the negative pressures, e.g. plastering on lathing, several instances of which at Hiroshima, and to a lesser extent perhaps at Nagasaki, were thought to indicate failures by suction at considerable distances, e.g. 12,000 ft. from the explosion. Mention is made in the table of the Appendix, of signs that the roof slab of Building No. 45 at Hiroshima had been lifted from the walls, the tops of which had moved outwards - (The movement of the near wall thus being towards the explosion.) - (See also the remarks on bridges) -

3.1.4 Screening Phenomena were observed, much as in normal HE blast incidents. They were most apparent at Nagasaki, where trees on the leeward side of hills were much less effected than those on the exposed sides and summits. Houses similarly survived on the leeward sides of the hills, e.g., at W, X, Y, Z, Map No. 4, at distances at which they would have failed had they been exposed. Screening effects by smaller objects were not often marked.

3.1.5 Diffraction Effects - were observed in many instances, showing that, as would be expected, complete screening was not always afforded. Trees partially screened round the shoulders of hills were uprooted or damaged. Buildings both small and large were found, particularly at Hiroshima, where window frames, doors and/or wall panels were observed to be bulged inwards both on the exposed and on the sheltered faces. At 4300 ft. from G.Z. at Hiro -

shima is one example which is listed in the Table in the Appendix. Another illustrative example was a small single-storey treasure-house. It contained seven separate compartments. The three steel-framed doors on the front face were bulged inwards as would be expected. The doors Nos. 1 and 4, on the rear face were bulged inwards, No. 2 was almost unaffected and No. 3, which had evidentally been open, was badly twisted and damaged. Similar bulging found in large buildings may occasionally be associated with suction phenomena, but it is not always clear what the action has been.

3.1.6 Reflection Effects - These were apparent in many incidents. One noticeable feature seen on the flat roofs of many large buildings was the overturning of the parapet wall along the side remote from G. Z., and the unaffected parapet wall on the near side. This shown in Photo No. 1, and probably indicates reflection from the roof slab supplementing the direct blast wave from the high burst. No doubt diffraction of the blast occurred at each wall, but the reflected blast was more than sufficient to counterbalance it on the leeward wall. The dishing of the roof slabs was also more pronounced on the leeward side.

In many instances, it was difficult to differentiate between suction effects and reflection effects; thus both at Hiroshima and at Nagasaki, some bridges gave indications of having been lifted and displaced sideways - and both suction and reflection phenomena may have been present. (See Table of Appendix).

3.2 TYPES OF STRUCTURE AND DAMAGE -

3.2.1 R.C. Framed Buildings - There were many buildings of reinforced concrete framed construction in the two cities, and they varied considerably in type. It may be convenient to classify them as

(i) heavy reinforced concrete in public buildings such as schools, office buildings, etc.,

(ii) exceptionally heavy or special construction,

(iii) light framed construction in industrial buildings.

All types resisted the blast effects reasonably well, as would be expected from experience of their behaviour when subjected to ordinary HE attack. In the atomic bomb attacks, however, the explosions took place at such a height above the ground that the blast was directed almost vertically downwards on the buildings nearest zero - and even on the more distant buildings the blast had a large downward component. Consequently the behaviour of the roof slab had a great influence upon the behaviour of the building- much more so than in European experience when the bombs usually exploded at or near ground level. A further difference in behaviour is due to the much longer duration of the positive phase of the blast wave than that of smaller bombs. Thus many smaller buildings were, in a sense, engulfed in the positive wave and crushed from all sides almost simultaneously. With larger buildings, as already mentioned, the whole structure is racked, by the excess pressure distributed over the more exposed wall, and the floors and roofs acting as struts are subjected to compression forces as they transfer the pressure to the leeward stanchions and walls. (See Photo No. 4). For this type of damage the amount of screening and the orientation of the building has marked effects.

The positive pressure was also able to penetrate more readily into the interior of buildings, after destroying windows or panels in the exterior walls. (See Table of Appendix) Building 28, Target at Nagasaki, 3,800 ft. from G. Z.) Thus, in two or three instances, while the intermediate floors remained undamaged, presumably due to the approximate equalisation of pressure on their upper and lower surfaces, panels of the ground floor were demolished or bulged downwards into the basement, since the lower face of this floor was not exposed to the blast, e.g., Building 12 at Hiroshima and BBB at Nagasaki. This has happened in England, when a large instantaneously fuzed bomb has exploded at a short distance away from a framed building.

(i) Heavy Construction - A selection of incidents is given in the Table of Appendix. It will be seen that at Hiroshima, Building 12 at 600 ft. from zero, there was extensive demolition, the roof slab being punched downwards, in some cases without demolishing the columsn, which remained projecting above the fallen floors and roof. (Photo No. 7). Building No. 21 at 1100 ft. had suffered partial collapse, though this building was of a rather special character and the construction was defective. At Nagasaki the school building, W at 1600 ft., had suffered partial collapse. (Photo No. 5) It will be noted that the roof beams were buckled upwards, so that the major cause of failing was the inability of the roof to function as a strut and transfer the lateral forces from the exposed to the sheltered side of the building. The direct downward pressure of the blast on the roof was insufficient to prevent the buckling in the upward direction. Building BBB at 1600 ft., a portion of which was steel-framed, also suffered partial collapse, the roof girders failing by buckling under the end load, much as did the roof in Building W.

Building M at 2200 ft. suffered structural damage, but no collapse. Similarly, a three-storey office block (4) at 3600 ft was undamaged structurally except for a few cracks in the roof beams and deflection outwards of the remote parapet. The main frame of Building J at 3800 ft. was undamaged, but the internal walls and panels were bowed or demolished. The radius for partial collapse for this type of reinforced concrete building is thus probably less than 2000 ft. though some structural damage - possibly repairable without reconstruction - may occur up to 2200 ft. or so. Even at 600 feet the collapse of Building No. 12 though extensive was not complete - nor was that of the building at 1100 feet.

(ii) Exceptionally heavy construction at Hiroshima in particular, many of the reinforced concrete buildings were abnormally strong in comparison with European designs. Thus, in Japan, the regulations specify that roofs of schools and similar buildings should be designed to carry safely a minimum load of about 70 lb. per sq. foot, so that they might be used as gymnasia, etc. The roof of one building at 1200 ft. from zero (was loaded with 12 inches of ashes and 6 inches of sand, and although subjected to the highest downward thrust of the blast from the atomic bomb, was structurally unaffected by it. It was not possible to obtain drawings of most of the Hiroshima buildings, so that except where the structure was badly damaged, details of the reinforcement could not be obtained. Since, however, some were undamaged at comparatively small distances from G. Z., where they were subjected to the highest intensity of direct downward blast, and since those buildings of which plans were procurable were of excessively strong construction, it is probable that these undamaged buildings near G. Z. owed their safety largely to the fact that they were exceptionally strong, and also that they were not subjected to such large lateral forces as were buildings more remote.

For example, in Building No. 6, 300 ft. from G. Z., at Hiroshima, though it was gutted by fire, suffered no structural blast damage. One seven-storey building, No. 23, at Hiroshima, was of special construction and although only 1000 ft. from G. Z. (distance from A. Z. 2250 ft.) did not suffer any serious structural damage except that to the roof.

The behaviour of Building No. 95 is also noteworthy. The "portal" construction is designed to give stiffness to the frame, and though crackling occurred in some of the frame members, and wall and roof panels deflected to some extent, no collapse occurred at 1500 ft. from G. Z. (2500 ft. from A.Z.).

(iii) R. C. Light Framed Single-storey Buildings - These buildings were mostly of lighter construction and failed at considerable distances, through mass distortion. An interesting example described in the Table and illustrated in Photo No. 6 was that in the Mitsubishi Steel Works (Target A, Building 30). The roof consisted of a reinforced concrete arched rib with a steel tie. Though 4,900 feet from G. Z., several bays of the structure collapsed, the truss failing under the combined action of the downard thrust of the blast and the compression forces.

An ammunition store at 4300 ft. from G. Z. at Hiroshima and shielded on two sides by high earth blast-walls suffered considerable roof damage, and steel doors were bulged inwards both on the face nearer the earth bank and on the face remote from zero. The walls of the building were not directly affected, though damaged near the eaves by buckled roof beams. The behaviour of the blast in this incident is peculiar, since a tree and a mud wall some 15 to 20 ft. beyond the building had collapsed towards zero.

Building No. 76 at 5900 ft from zero was another example of light reinforced concrete construction. It was about 25 ft. high to eaves, of a single storey: the wall panels were 12 inches thick and badly buckled, their large area no doubt being a contributory factor. It was also largely unscreened by other buildings, and the panels faced zero.

3.2.2 Steel-framed Multi Storey-Buildings - Buildings of this type were uncommon. None were exposed to risk in Hiroshima and one only in Nagasaki (See Target A in Table). This building was at 4,750 ft. from G. Z., and suffered damage to the roof. The roof slab rested on built-up N type girders, and these were badly buckled, the slab dishing 3 feet. The remainder of the frame was apparently unaffected, except the internal stanchions of the 4th floor. It is impossible to compare the relative efficiencies of steel and reinforced concrete frames from such little data. Heavy R. C. buildings at this distance, 4700 ft. from G. Z., were structurally undamaged.

3.2.3 Steel-framed Single-Storey Buildings - There were few such buildings at Hiroshima, and those were mostly small. Nagasaki, however, contained a number of large industrial plants with steel-framed shed-type buildings at distances varying from 1600 ft to more than 3 miles from the G. Z.

All the plants of any importance were in the broad river valley running north from the harbour, with the ship-building area in the south, the Mitsubishi Steel and Arms Works near the centre and the Torpedo Plant to the north. Generally, the steel-framed buildings were of the gantry type, and of normal design. There were some slight differences from normal European construction, and these may have had some secondary influence upon the radii of structural damage. Thus the corrugated iron sheets were of thin gauge metal, and secured with ¼" diameter bolts as opposed to 3/16" in England, and the purlins were rather more closely spaced. Asbestos-cement sheeting was used on many buildings.

As mentioned earlier, a very striking feature of Nagasaki was the "mass effect" of the blast on the steel-framed shed type and other buildings. The nearer buildings were pushed over bodily (Photo No. 10) and total collapse resulted, while at somewhat greater distances (Photo No. 9) the entire building would be distorted and lean away from zero.

The areas of effectiveness of the bomb in producing "mass effect" and "structural damage" were estimated by the average circle method described in REN.137 and REN.406, and gave the following approximate values for Nagasaki:

Area of Effectiveness for Mass Effect - 1500 acres -

Area of Effectiveness for Structural Damage- 2500 acres -

The mean radii corresponding to these areas are

Mass Effect = 4700 feet,

Structural Damage = 5950 feet.

Some buildings suffered mass effect at 5000 ft. or more from zero, while other buildings at lesser distances suffered only minor structural or superficial damage. One reason for this is that with the long duration of the positive phase of the blast wave, buildings with resistant coverings such as corrugated iron or timber sheetings are more susceptible to damage than are comparable buildings covered with a sheeting such as asbestos-cement. The resistant coverings transfer a high proportion of the positive blast pressure to the structure before they themselves fail, whereas a friable covering is broken before it has had time to transfer much of the load to the structure. This effect can be seen in Target 3 (1) in the Table of Appendix where the building was appreciably distorted at 5280 ft. from zero, the walls being constructed of R.C. panels, and therefore much more resistant to blast than usual. Target 3 (2) received superficial damage only, this building being sheeted with asbestos cement. Other factors affecting the behaviour of a building include its orientation and shape, and the extent and disposition of wind-bracing.

At Nagasaki, in only five out of some fifty buildings did fire contribute to the damage to the structure. At Hiroshima, where the buildings were smaller and mostly surrounded by domestic property, fire was responsible for a large amount of the damage. At Hiroshima, however, some buildings enabled estimates to be made of the areas of effectiveness of the bomb in that city, and though the data were somewhat scanty they confirmed the conclusions based on the evidence at Nagasaki, which have alreadby been stated.

In the Table a selection has been made of illustrative examples. A fuller account will be prepared later as a R.E. Note.

3.2.4. Buildings with Load-bearing Walls - These buildings, which are not numerous, are of various types - some being quite small with 9" - 13½" walls and others public buildings of massive construction such as the Roman Catholic Cathedral at Nagasaki. (Photo No. 8) The secondary effects of fire have in a number of instances contributed to the structural damage, so that it has been almost impossible in such cases to differentiate between this damage and that attributable to blast. The wreckage of the Nagasaki Roman Catholic Cathedral 1700 ft. from G.Z. is shown in Photo No. 8. Fire was undoubtedly responsible for much of the damage in this instance, though strong blast effects are apparent. One reinforced concrete dome (N.W.) has been overturned and lies, unbroken, at the foot of the hill upon which the Cathedral stands. The other can be seen lying overturned within the general debris inside the building. The exact mechanism of failure is not clear, but such heavy masses might quite well cause general collapse, if the supporting walls of brickwork were badly shattered by blast or disrupted by collapsing roof trusses.

Most of the structures with load-bearing walls were industrial buildings, mainly of one-storey height, the roof being carried on timber or steel trusses. The behaviour of the buildings depends to a large extent upon the orientation and upon the behaviour of the roof trusses. There are too few examples and too many variables to analyse the Hiroshima and the Nagasaki buildings completely and independently, and judgment depends upon previous experience. To illustrate, a few examples are described in the Table or Appendix. Thus Target A at Hiroshima comprised two buildings, one of which, B, collapsed completely, while the other, A, suffered no structural damage, at 6200 ft. Similarly in Target 123 at 7200 ft. the roof trusses collapsed, the end gable collapsed, and the various walls were cracked at the junction with cross walls. Target AAA at Nagasaki, 8500 ft. from Zero, suffered no structural damage to walls and piers while Target D at 6500 ft., with thicker walls collapsed. Basing their opinion on the behaviour of these and other buildings, the team consider that the radii of damage for ordinary British housing would be of the order of -

	Hiroshima	Nagasaki
"A" damage - demolition	(3000 ft.)	(3000 ft.)
"B" "	5000 ft.	5000 ft.
"C" "	7000 ft.	7500 ft.
"Ca) "	10,000 ft.	13,000 ft.

3.2.5 Japanese Houses - See Plate in Appendix) -

These buildings are of timber construction with vertical posts 4" to 6" square, resting on a continuous wood sill. The roofs are not trussed in orthodox European fashion, but consist of heavy tie beams (6" X 6" to 12" X 12") carrying vertical supports upon which rest the purlins. There may be a second main beam at right angles to the main tie, but often the construction is weakened by the presence of a joint in the length of one or other of these main members. The roof covering is normally of pan-tiles bedded in mud on rough ½ inch boarding, below which are the spars resting on the purlins. The solid infilling between the wall posts is of mud about 3 inches thick, reinforced with interlacing bamboo rods, but a great proportion of the walling consists of light wooden frames with paper or, occasionally, thin glass panels. Thin ¼" horizontal boarding was frequently employed on the outside face to protect the mud walls. At Hiroshima, the zone of complete collapse due to blast was symmetrically disposed around the zero point, the average radius being about 6750 ft. Within a radius of about 5850 feet, fire had completed the destruction. At Nagasaki, the symmetrical distribution was not so immediately apparent, but the map shows that if allowance is made for limitations imposed by built-upness, there is nothing to suggest lack of symmetry in the blast effect. The average radius of structural collapse was about 7450 ft. The complete destruction due to the combined action of blast and fire at Nagasaki was less symmetrically disposed as is seen on the map. To the South the fire damage extended to 7500 - 8000 ft. on the west side of the river, but to about 11,000 ft. on the east side. The area to the north consisted largely of industrial buildings, so that although fire and blast together were responsible for destruction up to 7500 ft. say, this would not necessarily have been the limit had the target resembled that to the S.S.E. of G.Z.

Beyond the limits of complete collapse, there was a zone in which the buildings suffered structural damage (a) by distortion of the frame without fracture of the members, and (b) by fracturing of structural members, usually at some accidental point of weakness. The radius of structural damage in one or other of these ways, was about 7900 ft. in Hiroshima say 8600 ft. in Nagasaki. (See Photos 11 & 12).

Beyond or overlapping the range of structural damage was serious non-structural damage to roofs, wall panels, partitions, etc. The radii for this were about 7900 ft. at Hiroshima and 9000 ft. at Nagasaki. Beyond this zone, superficial or minor damage occurred up to very large distances. No good estimate of the extent could be made on account of the limitations of the sites. At Nagasaki, for instance, the meteorological station, in an exposed position on a hill, about 16,000 ft., almost due south of zero, had all the windows broken on the near face and many of the window frames broken and displaced. A large proportion of the roof was stripped of tiles.

The blast damage radii quoted above may be tabulated as follows:-

	Hiroshima	Nagasaki
Collapse due to blast	6750 ft.	7450 ft.
Structural damage without collapse	7900 ft.	8600 ft.
Serious non-structural damage	7900 ft.	9000 ft.

3.2.6 Timber-framed Single-storey Buildings - Such buildings were very common boht in Hiroshima and in Nagasaki. They were based upon a wood sill bolted to a low concrete foundation wall; the uprights were frequently about 4" X 4" spaced 6 feet apart. The roof was often tiled and carried on steel or heavy timber trusses. The buildings, unless adequately stiffened by internal partitions, etc., were very susceptible to "mass effect", distorting readily at much greater distances than the domestic property. Collapse was most often due, either to excessive lateral distortion, or to the failure of the timber uprights in the walls, the mortices and tenons, in particular, being points of weakness. In such cases the roof collapsed without much lateral displacement, and must have been the cause of many casualties.

3.2.7 Bridges - Sime 49 bridges were examined within a radius of about 10,000 ft. from G.Z. at Nagasaki. At Hiroshima, only one bridge, No. 29, was destroyed by the explosion, and this was in such a bad state of repair initially that collapse was inevitable; nine other bridges of timber construction were destroyed by fires following the explosion; the remainder, 31 of which suffered no structural damage, continued in use without repair. At Nagasaki four road bridges were rendered impassable, and two bridges 0 one carrying the railway and the other a tramway - were so displaced and deformed that they were unusable until repairs had been executed.

The most spectacular bridge damage at Hiroshima was that suffered by the T Bridge Nos. 23 and 24. The main girders were practically undamaged, thought there was evidence that they had been lifted. The decking, however, had obviously been separated from the girders, lifted several feet, and displaced laterally. One footway slab had also received an appreciable longitudinal displacement. (See Table)

At Nagasaki, the majority of the road bridges were constructed in reinforced concrete and were of relatively short span. They were usually of the beam and slab type with 7" thick deck, and supported on r.c. framed piers which were often apparently not secured to foundtions. The railway bridges were of the plate girder deck type, normally single track, with the sleepers fixed directly to the stringers. Of the road bridges rendered unusable, one No. 5 (2325 ft. from zero) was of three simply supported spans in reinforced concrete. One span was destroyed and lies fractured at the centre, some 7 feet upstream (i.e. away from zero) from its original position. The other spans, piers and abutments were apparently undamaged. A second concrete bridge, No. 11, (1950 ft. from zero) was of four spans. The right hand span of reinforced concrete, simply supported, and weighing approximately 18 tons, had been overturned and lies downstream from its original position. The remaining spans were completely destroyed but these were of lighter construction - r.c. slabs on steel girders. Some of the girders are still in position, but the road slab lies on the river bed, distributed over distances up to 50 yds. downstream, away from the explosion. The tramway bridge, No. 26, and the railway bridge, No. 27 (see Table) both of which were rendered unusable were of the plate girder type and about 900 ft. from zero. The damage was caused by the relative movement of the deck system and the main girders. No. 26 was displaced bodily about 4 ft. away from the explosion, and though some distortion occurred it could be put back without too much difficulty.

In Bridge No. 7 (1650 ft. from G.Z.) the left hand middle stringer was fractured and in Bridge No. 9 several of the longitudinal beams were broken at the quarter points (see Table of Appendix) The action of the blast on the bridges was not always easy to elucidate. Sometimes it was clear that damage had been caused by the downward force of the blast, but in many cases, as has been mentioned, the whole superstructure or in other cases the deck slab only had been lifted bodily and displaced sideways. (See Photo No. 14). The parts which were subjected to this movement usually had either no or very little anchorage provided to resist upward movements, and little more than frictional restraints to prevent lateral movements. It may be, therefore, that the movements in some cases, were largely due to the rebound following the more or less elastic downward movements due to the blast. Suction, windage and reflection phenomena also have contributed varying amounts under different circumstances. The "rebound" effect, in this case without any structural damage being caused, was illustrated by the minor damage suffered by Bridge 22 at 500 ft. from G.Z. at Hiroshima. The bridge was of deck-type construction, with four main steel longitudinal girders. It was of cantilever construction of three spans. The shore-spans comprised the anchor arms, and the centre span comprised two cantilever arms with a suspended span connection them. The damage was of a minor character, the stones of the eight ornamental pilasters (two at each abutment, and two at each pier) being displaced in a strikingly symmetrical manner about the bridge centre,and the anchor arms lifted and slightly displaced at the abutments. Evidently the centre span had depressed and recovered under the blast, and shaken the whole structüre. Generally, at Nagasaki, no displacement of the bridge occurred beyond 2400 ft., and the Hiroshima experiences were consistent with this.

3.2.8. <u>Air Raid Shelters -</u> The Japanese Government issued suggestions of certain simple civil defence protective measures, but apparently did not undertake the provision of shelters for the civil population. At Hiroshima, there was, however, some attempt to provide public shelters along the road verges of some of the principal streets, includihg those immediately around G.Z. These shelters were of the partly-sunk, earth-covered, timber-framed type, (Photo No. 15) though the framing details vary. In some districts in Hiroshima also, above-ground shelters of the same general type of construction, earth-covered had evidently been eredted under some form of central control, as the design and the covering material was of the same type throughout, the latter having been imported from a distance. At Nagasaki no evidence of such concerted action was apparent.

At Nagasaki where the conditions were favourable, a considerable number of small caves had been excavated into the hillsides. Occasionally, small concrete-lined shelters, sunk or semi-sunk were formed at factories, and occasionally blast walls of earth, revetted with timber were provided at entrances to caves, etc. At one or two sites, reinforced concrete surface shelters had been built for control-posts; and one or two buildings had heavy timber shuttering to protect windows. In one works, portable r.c. blast walls had been introduced to protect machinery. These features were exceptional, and presented no novel or outstanding ideas.

A survey was made of the damage incidence to the small semi-sunk air-raid shelters at Nagasaki; these shelters were mainly about 8 ft. x4 ft. in plan, with about 4 ft. headroom. They were built with wood framing of a variety of sizes from 4" diam. poles to 2" planks and the earth cover, which seldom exceeded 18 inches was carried on boards or more usually on bamboos. A popular size of bamboo was about 1 inch diameter, and occasionally split bamboos, laid touching, of 3" to 4" diameter were used. The details of the survey are not included in this report, but undamaged shelters were given a figure of merit of 1, collapsed shelters of Oand damaged shelters of 0.5. All shelters ground shelters of the same general type of construction, earth-covered had evidently been eredted under some form of central control, as the design and the covering material was of the same type throughout, the latter having been imported from a distance. At Nagasaki no evidence of such concerted action was apparent.

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A graph showing the results is given in Fig. 1. It will be seen that at 900 ft. from the bomb, the roofs of the shelters had a 50% chance of survival, and almost a 100% chance of survival at 3000 ft. or so. In fact, since they were not subjected to earth-shock effects, the shelters were relatively efficient, since they possessed the properties of massiveness and flexibility which are so valuable in providing resistance to blast. Well constructed shelters of this type would have behaved much better even than the curve in Fig. 1 suggests.

In many instances, the timber framing near the entrances to the shelters was charred and carried flash-burn marks at considerable distances.

3.2.9 Machine Tools - Factory surveys were made of the damage to machine-tools, both in Hiroshima and Nagasaki. The data require a considerable amount of study and a fuller report will be prepared later, but tentative conclusions have been drawn.

The severity of damage to machine-tools is closely related to severity of building damage, and since the machine-tools are housed in a wide variety of buildings they have been classified under three main headings - those in timber-framed workshops, those in steel-framed workshops, and those in reinforced concrete framed sheds.

The causes of damage are mainly:-

(a) Fire -

(b) Overturning -

(c) Debris -

(d) Mass movement of structures -

(a) Fire was a major cause of damage only in timber framed workshops of the smaller types, and in small steel-framed shops associated with dwellings. The fire risk here was high either on accountof un-satisfactory factory procedure or due to the presence of the associated domestic structures. Fire destroyed small timber workshops, without exception, up to a distance of 7000 ft.from G.Z. It was impossible to determine the cause of fire in these shops. Primary fire probably occurred, but the coincidence of the limiting distances at which destruction by fire and mass distortion of the buildings by blast occurred suggests that secondary fires were of importance.

On the average, 40% of the machine-tools in timber-framed workshops destroyed by fire were seriously damaged by fire effects alone.

(b) Overturning of machine-tools. A number of machine-tools, particularly those in timber framed workshops, were serûously damaged by overturning as a result of lateral mass movements of the buildings. In some instances, the overturning movements was applied through the driving belts, when shafting was displaced with the building frame. 10% of the light engineering machine tools housed in timber framed workshops which were distorted or demolished, were seriously damaged by over-turning.

(c) Debris was an important cause of damage to machine tools only in reinforced concrete sheds. This damage was exclusively due to the collapse of roofs and walls. 75% of the light enginering machine tools, within the areas of collapse, were seriously damaged by debris.

(d) Mass movement of structures seriously damaged machine tools housed in steel-framed buildings. Sometimes the damage was caused by the collapse of the structure upon them, and sometimes by the lateral forces exerted upon them under the conditions of mass distortion of the buildings. These causes were the main sources of damage to machine tools in steel-framed workshops. Subsequent exposure to weather was also of major importance.

The "areas of effectiveness" for serious damage to machine tools, due to the atimic bomb, have been estimated as given below:-

(i) Timber Framed Workshops -

(a) small workshops

Light Engineering	1700 acres	Approximate radius	4850 ft.
Heavy Engineering	(1300 acres)	"	4250 ft.

(b) Shops associated with large factories -

Light Engineering	(800 acres)	Approximate radius	3300 ft.
Heavy Engineering	(640 acres)	"	950 ft.

(ii) Steel Framed Workshops -

Light Engineering) Heavy Engineering)	25 to 75 acres	"	1000

(iii) Reinforced Concrete Sheds -

Light Engineering	(2000 acres)	"	4750
Heavy Engineering	(800 acres)	"	3300

3.3 PUBLIC UTILITIES -

Under this heading are given brief descriptions of the damage caused by the atomic bomb to:

(1) Railways and tramways -

(2) Road Vehicles -

(3) Electricity Supplies -

(4) Water Supplies -

(5) Gas Supplies -

(6) Sewerage System -

As would be expected from a blast weapon, airburst, the damage inflicted on underground services was negligibly small.

3.3.1. Tramways and Railways -

(i) Tracks were not directly effected by blast, except where associated with damage to bridges. At Nagasaki, where the railway was closer to G.Z. than at Hiroshima, a considerable number of the sleepers were burnt or charred.

The sleepers were, however, often in a bad condition and more combustible than one would ordinarily expect. As a result of such fires the rails were liable to buckle or twist, and the track become unusable without repair. Tracks were liable to be damaged to some extent by secondary causes, e.g., the displacement of rolling stock, or blocked by débris

(ii) Buildings such as those at the stations suffered damage appropriateto their construction or distance from zero, both at Hiroshima and Nagasaki.

(iii) Tramway rolling stock at Nagasaki suffered a considerable amount of damage; some coaches were derailed, others had their wooden superstructure shattered by blast, or destroyed by fire,* or debris. At Hiroshima, many tram cars operating between 9000 ft. and 15000 ft. from G.Z. suffered damage to glass and overhead gear. Some also had burnt out motors. The tramway manager stated that out of 85 motor buses, 25 were damaged or destroyed by the bomb and 18 burnt out by the fire.

(iv) Telegraph and other poles or standards carrying overhead wires and cables were blown down, often being fractured near ground level. At Nagasaki, it was noted that standards within about 800 feet to the north or south of G.Z., remained vertical, while beyond this distance, e.g., as far as 2700 ft. to the south of G.Z., the standards were overturned. The reason for this would appear to be that near zero, the blast was directed almost vertically downwards and had little overturning effect on the poles.

(v) Overhead wires and cables were broken and many were still unrepaired. It was not clear to what extent they had been broken directly

* The Tramways Manager stated that some Trams were burnt purposely to cremate those passengers who had been killed.

by blast or broken by the fall of the supporting standards,. Since the standards had almost always fallen away from zero, it would appear most likely that their failure had occasioned the breakage of the wires rather than the reverse. The signalling equipment was stated to have been destroyed, and since replaced.

(vi) Bridges have been discussed in 3.2.7.

3.3.2. Road Vehicles -

There were no available records of damage to vehicles and the extensive fire in the centre of both cities made it difficult to reconstruct the fate of the vehicles that remained. The wreckage of vehicles found by the roadside fell into one of three classes

(a) abandoned before the bombing and burned out during the bombing,

(b) wrecked by the bomb and subsequently burned out,

(c) abandoned after the bombing.

Though it was impracticable to make a quantitative study of vehicle damage, it may be useful to discuss a few specific examples.

In Hiroshima there were two unburned vehicles that appeared to have been wrecked by the bomb. One was a Dodge Sedan which was on the road at 1200 ft. from the centre. It lay in an unburned island and all other evidence pointed to it having actually been at that place when the bomb went off. The body was damaged beyond repair; the roof(a solid steel one) was pushed down to the level of the seat tops and doors and bonnet were pushed in. There was no evidence of gross structural damage to the chassis. The other, a similar vehicle at 3000 feet, seemed to have suffered only severe denting of the foof before being burned out. Two heavy American sedans at 3150 feet appear to have suffered similar damage before being burned out.

A Buick 8 at 6300 ft. had only slight bending of roof and body panels and broken windows, and there was nothing to suggest that it was immobilized by the bomb.

A general inspection of the vehicles in the area near G.Z. at Hiroshima suggested that the vehicles at 1500 ft. to 3000 ft.show more blast damage than those closer in or farther out. All but the one mentioned above were burned out.

The Public Works Engineer at Hiroshima says that the newspapers reported that 200 vehicles had been destroyed including 50% of all the buses and 60% of all the trams. He thought that thoseefigures were low. He claims to know that at 4650 ft. some cars went on running after the driver had been killed or seriously injured by the bomb.

The figures given by the City Hall authorities for vehicle damage in Nagasaki are:-

Classification	Number of Vehicles Before	Destroyed	Remaining
Civilian Autos	19	6	13
Trucks	105	26	79
Government	13	4	9
Industry	39	11	28
	176	47	129

It is worth noting in connection with these figures that there were probably no petrol-burning vehicles in use. They had all been converted to heavy oil or charcoal, coal, etc. The use of a heavy, single cylinder, horizontal, heavy oil engine in trucks is common to Japan. This would greatly reduce the fire risk and thus reduce the total vehicle casualties.

It is dangerous to generalise from such inadequate data but as a rough approximation it seems likely that ordinary passenger vehicles would remain in running order at 6000 ft. or less. More rovust army vehicles might easily survive without vital damage at half this distance unless hit by buildings, etc. It seems likely that the driver will usually be more severely damaged than his vehicle.

3.3.3. Electricity Supplies -

Both at Hiroshima and at Nagasaki, electricity supplies were cut off from the effected areas almost immediately. It was not possible to determine with any degree of confidence, whether the cut-off of the main supply was sufficiently rapid to prevent short-circuiting and the start of secondary fires in buildings within the area. The failure of the main supply was due (a) to the cutting of the high tension cables, and the wreckage of the steel lattice pylons. (The latter were wrecked up to 3 km. from the bomb at Hiroshima.) and (b) to the damage suffered by switch-boards and switch gear in the substations by debris. The transformers and the instruments were not usually much damaged. Of the ten substations in Hiroshima, three were put out of action and from the remainder it was possible to supply lighting to the houses in the more distant parts of the city, e.g., 4000 yds. or more from zero. At Nagasaki, the damage to substations was similar. Where the building was demolished or partly demolished the debris had smashed the switbh-gear, but otherwise transformers and instruments escaped. The main transformer station, aboutl mile from zero was severely damaged by blast, and the switchboard smashed by the debris.

3.3.4. Water Supplies -

Neither at Hiroshima nor at Nagasaki was any serious damage done to underground mains. It was stated that cast-iron mains had been broken in one or two cases, the fracture being such as one would expect by bending -not a failure by crushing. In other cases, comparatively few in number, the leaded socket joints had bgen loosened and leaks developed. Much more damage had been caused to underground mains by the heavy American road traffic, since the occupation of the cities. In some instances, watr mains were broken, where they cross the rivers at bridges which were displaced by the blast. The pumping stations were too far from the explosions to have suffered serious damage, and though the pumping plant at Hiroshima was out of action for some weeks, due to failure of the electrical supply, the pumping machinery did not suffer.

3.3.5. Gas Supplies - At Hiroshima, the gas-works were situated 6500 ft. from G.Z. The buildings were seriously damaged and some were demolished. The two gas-holders suffered blast damage, the crowns being dished downwards and torn open. The framework was not distorted. It was stated that the escaping gas burnt like a huge torch, but that no explosion took place. Gas-oven doors were damaged and production stopped. Underground mains had not been examined, but except where they crossed bridges, no damage was expected.

At Nagasaki, the two gas-holders of one plant, 6500 ft. from G.Z., were dished in at the top, and it was thought possible that as at Hiroshima the lack of lateral distortion was to some extent accounted for by the long duration and length of the positive phase of the blast wave.

The single gas-holder at another plant, about 3100 ft. from G.Z., was wrecked, the structure being badley distorted away from zero. It was stated that an explosion had occurred in this case, but the evidence for it was not very convincing.

As at Hiroshima, very little if any damage was thought to have been caused to underground gas mains, except where they crossed bridges.

3.3.6. Sewerage Systems -

The sewerage pipes at Hiroshima, buried to an average depth of about one metre, are not thought to have been damaged. Two outlet trap doors in the river banks are said to have been torn from their hinges. At Nagasaki, no sewerage system existed.

3.4. ESTIMATION OF EQUIVALENT CHARGE OF T.N.T. -

Some attempts have been made to estimate what amount of T.N.T. would produce effects comparable with those of the atomic bomb.

The calculations are somewhat academic and of doubtful value.

Figures for the blast-pressure/time relationship of large bare charges of T.N.T. are not available, though we have some figures by Sachs and Bidelman for the peak pressures at various distances from bare charges of 11,070 lb. and 20,280 lb. From these it is deduced that a peak pressure of 1 lb. per square inch occurs at a distance of r feet where $r/W^{1/3} = 38.6$. It is estimated in previous pages that C_b damage to houses of British construction would be likely to occur at 7000 ft. for the Hiroshima bomb, or 7500 ft. for that dropped at Nagasaki. It is further concluded from tests on 9" walls, that a static pressure of about 2 lb./sq. inch will produce cracking. The face-on peak pressure of the blast wave may be taken as 2 lb./sq.inch if the side-on peak pressure is 1 lb./sq.in. Hence the atomic bomb must be equivalent to a quantity of bare T.N.T. larger than

$(7000/38.6)^3$ lb. = 2660 tons at Hiroshima, or

$(7500/38.6)^3$ lb. = 3270 tons at Nagasaki.

According to AC 7810 the optimum height of burst for a 4000 lb. HC bomb lies between 30 ft. and 70 ft., and the mean area of visible damage is then increased 50 to 80 per cent. The height of burst of the atomic bomb was apparently considerably higher than the optimum height, i.e., if it is considered as equivalent to 3000 tons of T.N.T., the equivalent of the 70 ft. height quoted would be only 900 ft., and if equivalent to 10,000 tons of T.N.T. the corresponding height would be 1370 ft. instead of that actually used - 1750-2000 ft.

It may be that some increase in visible damage resulted from the airburst, but the increase would seem to be small, and these calculations do not warrant the introduction of this refinement.

If we consider what charges of T.N.T. would be required to produce the collapse - and not merely the cracking - of 9" wall panels, then the modified impulse criterion for blast damage may be applied, as described in R.C. 349. There were undoubtedly some collapses or bad distortion of brickwork up to the limits of C_b damage.

Other direct data not being available, the duration of the blast wave has been taken from the curves for bombs in R.C. 289.

On these bases, the bare charge of T.N.T. required to produce collapse of 9" brickwork at 7000 ft. is estimated to be 5000-6000 tons, and at 7500 ft., of the order of 10,000 tons.

At these distances, it is obvious from the figures, that the efficiency of the charges falls off very rapidly - and it cannot be claimed that the radii of damage are judged with sufficient precision to make the estimates for T.N.T. very reliable.

A number of other estimates have been made, based on the pressures required to overturn gate posts, grave stones, tall chimneys, etc., but these give much lower values; the observational data are available and may repay further study and analysis.

A further estimate of the equivalent T.N.T. may be made from the figures for the area of effectiveness of the atomic bomb against targets such as steel-framed buildings. The usual figure adopted for English experience is that the mean effective area for structural damage is 1 acre per 1.25 tons of explosive in bombs. At Hiroshima the damage amounted to 2500 acres, so that if it is assumed that, as for the HE bombs, the area of damage is proportional to the weight of explosive charge, then the equivalent weight of the atomic bomb would be rather more than 3000 tons of T.N.T. This estimate is, however, unreliable -

(a) because the rule is derived from the charge in bombs where the charge weight ratio may range from 50 to 75 per cent -

(b) because of the long duration of the positive phase of the blast wave, the radius of damage does not increase as rapidly as $W^{\frac{1}{3}}$, as the previous calculations demonstrate.

The one consideration suggests that the figure of 3000 tons is too high an estimate and the other consideration that it is too low. The figure can thus only be regarded as a very crude one, and subject to revision when more data are available from the New Mexico and other tests.

4. NEW EFFECTS

4.1. THE TOTAL RADIO SPECTRUM -

During the chain reaction which constitutes the explosive process in atomic bombs, energy is radiated over a very wide band of wavelengths. There is ample evidence of powerful radiation in the heat bands beyond infra red, in the visible spectrum, and down to the penetrating radiation of short wavelengths identified with gamma rays. The spectrum over this band, that is the distribution of energy among the various wavelengths, is not known to us. We shall adopt what has become common usage and call the effect of heat radiation on any material subject to scorching flash-burn. To avoid the confusion caused by using the words "radiation" and "radio-activity" in a variety of senses, we shall refer to all penetrating short wave radiation as gamma rays.

As the name implies, the phenomenon of flash burn, that is of the heat effect of explosives, is not essentially new. There is direct heat radiation from any propellant powder or explosive filling, and it can cause burns beyond the flame zone. What is new is the scale of the effect from atomic bombs. It will appear that this has an important bearing alike on the incendiary and on the casualty effects of the bomb.

On the other hand, penetrating radiation of the gamma ray type is new both in kind and in origin; for it is not the accompaniment of all forms of the mass release of energy. For bombs air burst at these heights, its main contribution is to the casualty effect. But it will be seen that gamma ray emission from the fission products of bombs detonated at lower altitudes, or of penetrating bombs, might create a serious problem for some time after detonation.

4.2. FLASH BURN AND OTHER HEAT EFFECTS -

A wide range of materials was effected by the high temperatures and heat flux at Hiroshima and Nagasaki.

4.2.1. Polished Granite - was roughened where exposed to the heat radiation, retaining its polish only in the shadow of objects. (In Photograph No. 16, the shadow of a sitting man.) This phenomenon was widespread in Hiroshima, where a good deal of monumental granite is employed. It was found up to 1200 ft. or more from G.Z., and the Japanese reported it beyond 3000 ft. At Nagasaki, we found similar roughening at 1800 ft. from G.Z.; Japanese reports put the figure beyond 5000 ft. At Nagasaki also, we found igneous stone lining the side channels of roads near G.Z. to have flaked.

The roughening of granite is caused by the unequal expansion of its constituent crystals; for example, for the quartz crystals this becomes critical at or about 573°C. The depth of roughening or flaking is therefore an index of the surface temperature. Using this measure, the Japanese physicists estimated the ground temperature at 1500 ft. from G.Z. at Hiroshima to have exceeded 2000°C. immediately after the flash. This figure is based on their measurement of the flaking of granite to a depth of 1 mm. at this distance, which we were not able to confirm; and on assumptions regarding the duration of the flash which are necessarily crude. It should therefore be treated with reserve.

The Japanese showed us other geological specimens with similar unequal heat effects. We found like effects in pebbles. Samples of these and of the granite were collected.

4.2.2. Bubbling of Tiles - Two kinds of roof tiles were widely used on Japanese houses both at Hiroshima and at Nagasaki, and both were subject to marked heat effects. These took the form of raising bubbles on the exposed surface, the bubbles becoming smaller at increasing distances from G.Z. We found bubbled tiles at somewhat over 2000 ft. in Nagasaki, and up to rather less than 1500 ft. at Hiroshima. Japanese figures are 3000 ft. and 2000 ft. from G.Z. respectively. Japanese geologists estimated the average temperature for tile bubbling to be nearly 2000°C., and the minimum to be 1200°C. Specimens have been collected of these and other materials described here, which will enable us to make independent estimates.

4.2.3. Concrete and Mortar Renderings - The surface rendering of many large buildings had been reddened by heat radiation. At building No. 45 in Hiroshima, at 1250 ft. from G.Z., the shadow of a down-pipe of 4½" diameter consisted of a grey unaffected band about 4" wide. This was bordered by fringes in which the colours ranged through a light bright pink to the darker duller pink of the fully exposed wall surface. The total width was about 5" to 5½, but the edges were ill defined.

4.2.4. Road Surfaces - Particularly at Hiroshima, there were a number of asphalt surfaces which showed shadows cast by people who had been walking there at the time of the explosion. In general, shadows on such surfaces were now fading. Shadows of this kind, perhaps by reason of their macabre interest, were conspicuous objects of pilgrimage among visitors.

In some cases, the effect on surfaces of this kind was probably due to the fusing or burning up of surface dust: This was observed on pebbles, tiles, etc. Glazed tiles were also affected directly.

4.2.5. Treated and Untreated Timbers - These surfaces showed the most marked effect of scorching and charring and the clearest shadows as in Photograph No. 17. A convenient index is the scorching of telegraph poles, which was found to have a high degree of uniformity in all directions at Hiroshima, and to be fairly uniform north and south of G.Z. at Nagasaki. At Hiroshima, this scorching disappeared roughly at 9000 ft.; at Nagasaki, it extended in places to 10,000 ft. We did not identify the wood used for such poles, but it appeared to be some soft species of pine or cedar, indifferently treated. Shadow marks on other timber surfaces, of the kind illustrated, served in the majority of zero determinations, as described in 2.1.2.

4.2.6. Painted Timbers - Paint was found burnt from timbers, and the timber itself scorched, with no noticeable selection of colours; among the colours observed to have been burnt off were white, red, blue, green, and black. The painting of timber, however, is not common in Japan. In all timbers, the soft portions of the annual rings were charred more deeply than the harder portions.

4.2.7. Other Paints - Shadows - The black coating on gas-holders was particularly sensitive to flash burn, which gave it a polished appearance in place of the dull and sooty finish where objects had intervened to mask the heat radiation; photograph No. 13 is an example. These gas-holders were at approximately 6500 ft. from G.Z. both at Hiroshima and at Nagasaki, but the effect might, of course, have extended much further. A somewhat similar black coating on oil tanks of the Standard Oil Company, rather over 5500 ft. from G.Z. at Hiroshima, had apparently been added for camouflage, since large areas burnt off revealed a white shell design upon a red background of oil paint.

In all the preceding cases, "shadows" were cast by intervening objects when these shielded a portion 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. On occasion, the shielding object had been no more than a clump of grass or the leaf of a tree. Since it is known that vegetables within 3000 ft. of G.Z. or more was withered and burnt, it follows that the flash must have ended in a time less than that required for the grass or leaf to shrivel. While we cannot estimate the required time with accuracy, it may be assumed to be some fraction of a second. There is some medical evidence that a similar time was required for the build-up of the flash to its maximum intensity; this is concluded from the low incidence of direct injury to the eye ball, which suggests that people had time to close their eyes. A Japanese survey of August 11-12 found blistering of the eyeball in 20%, and blistering of the eyelid in 45%, of 106 cases examined at Hiroshima. Considering the different exposures of eyeball and eyelids, it may, however, be doubted whether this is significant. The Japanese also believe that some people had time to shield their faces with their hands. The Japanese physicist who had estimated ground temperatures from the flaking of granite had assumed 1/8 of a second as the time of build-up to maximum heat radiation, and 1/8 second as subsequent duration. These times are probably too long.

Where shadows were susceptible to precise measurement, for example the shadows of vertical or horizontal bars, they were in general 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; the best examples were to be seen on the gas-holders at Hiroshima, and on Bridge 19 there, where the shadow from the middle one of three equal and parallel sets of bars was barely perceptible and the highest had cast no shadow. While diffraction may have contributed to this effect, and some other evidence for diffraction was found, the main effect was no doubt due to the finite size of the radiating fire ball. Calculations based on a number of such measurements give the diameter of this fire ball at Hiroshima to have been of the order of 250 ft. A rather larger figure is obtained from one such measurement at Nagasaki.

The less sensitive surfaces occasionally showed shadows which were markedly wider than the objects which had given rise to them, because some or all of the penumbra had been sufficiently screened. A contributing cause to a number of shadow appearances may have been decrease on intensity of radiation during the expansion of the fire ball.

4.2.8. Fabrics - Many sensational accounts were in circulation of the manner in which clothing and paper had been charred and fired, and of the differential effect of colouring. It was possible at Hiroshima to examine a number of exhibits with care and, to our surprise, to confirm much of what we had heard. Among the materials seen were:

A white cotton blouse with pale pink sleeves on which there was a small pattern of green leaves and red flowers, each spray being about 3/16 of an inch in diameter. Over an area on the left shoulder the sprays were burnt out leaving holes. There was a larger surrounding area in which the flowers were partially burnt, and here the red had smouldered markedly earlier and more extensively than the green.

A white dress with blue polka dots, of which the dots had burnt over a large area, but the white was not scorched. On the edges of the area, dots had begun to smoulder, in each case at the centre of the dot.

A shirt of alternating dark and light grey stripes, about 1/8" wide, containing an area where the dark stripes were completely burnt out but the light stripes remained.

A kimono having a pattern of white lozenges on a blue ground, of which large areas were burnt and had had to be beaten out. This garment, like many others, was said to have been fired directly by flash. On the edges of the area of fire, the white lozenges had survived but the blue ground had burnt. Taking this in the light of the preceeding exhibits, the story of its spontaneous ignition seemed reasonable.

A piece of Japanese paper on which characters written in black ink had been burnt out at 7500 ft. On other such papers which we did not see, characters written in red ink were said to have survived where characters in black ink had burnt out.

These differences are in line with some known effects reported to us by Cmdr. Shields Warren; for example, that black cotton chars at about 200°C. while white cotton survives to about 230°C. They may be caused by differences in colour, in colouring materials, or both.

4.2.9 <u>Human Skin</u> - Eye witnesses state that people who were directly under the bomb in the open had their exposed skin so severely burnt that it was immediately charred dark brown or black. These people died within minutes or hours. At both Hiroshima and Nagasaki, burns on exposed skin were third degree or worse up to about 4500 ft. from G.Z. At 4500 ft. some escaped with second degree burns, but some third degree burns were reported as far out as 7200 ft. Mild second or first degree burns were reported as far out as 13,000 ft. from G.Z., and may have extended further.

In general, even thin clothing gave complete protection from flash burn. There were rare exceptions where clothing was stretched tightly over the underlying skin, say on the point of the shoulder, when on occasion there were skin burns through uncharred fabric. On other occasions clothing itself caught fire, sometimes without burning the underlying skin. But the general picture is of a close correspondence between charred clothing and skin; for example, the girl wearing the flowered blouse described above at 6000 ft. from G.Z. in the open, had second and third degree burns which were confined to the points at which the flower sprays had burnt.

The shadow of a wall, a building, etc. gave complete protection from flash burn. At Hiroshima, a detailed study now in progress of men in the prison, 6000 to 7500 ft. from G.Z., confirms that, allowing for some errors in placing people, those in the open were burnt, while those in buildings, or the shadow of buildings, escaped. A group of 580 workers marching across the Koi Bridge facing the bomb at a distance of 7200 ft. were burned, with the exception of three at the rear whom subsequent investigation shows to have been in the shadow of the eaves of a building. The burns were severe, up to third degree, and there were nine deaths.

4.2.10 <u>Vegetation -</u> The Japanese reported that crops above ground had been completely burnt at 3000 ft. from G.Z. at Nagasaki. Flash burns on trees were seen there at 8000 ft., and trees had been fired at Hiroshima in isolated positions beside the Castle Moat at 3500 ft. as shown in Photograph No. 19.

Where trees which had been stripped of foliage, by undetermined causes, were putting out new leaves at Hiroshima and Nagasaki, it was noticeable that the fresh shoots were frequently coming not from subsidiary branches but from the main trunk, as shown in Photograph No. 20.

4.3 THE FIRE PROBLEM -

Attention has been drawn to the great extent of fire damage in both cities. Fire was not confined to Japanese houses, but raged fiercely in many concrete buildings, machine shops and other buildings of fire-resistant construction. An investigation of the danger of similar fire in European areas was therefore of considerable importance. To this end, a detailed study was undertaken of the causes of fire, particularly in industrial, commercial, and public buildings. The greater part of this study was carried out at Nagasaki, where such buildings were less completely surrounded by burning Japanese houses. The possibilities which we sought to examine were:

(1) Primary fires caused by direct heat radiation-
(2) Primary fires caused by convected heat-
(3) Secondary fires caused by damaged heating appliances, electrical failures, etc.
(4) Fire spread from adjacent buildings by radiation, convection, or flying brands.

4.3.1. Heat Radiation - Evidence presented under 4.2., particularly in sections 4.2.8. and 4.2.10., made it important from the outset to investigate heat radiation as a possible cause of fire. Examples were therefore sought in which other causes might be eliminated. Many examples of fire were found at both Hiroshima and Nagasaki which it was difficult to account for, except by heat radiation. These included telephone poles, etc. in isolated positions, e.g., (in a paddy field), posts and poles burnt only at some feet above the bottom or below the top and others burnt at the top only. (See also Photo. No. 19) An interesting instance of an isolated fire occurred at Target C, Building No. 8, at 5700 ft. from G.Z. Here vertical unpainted boards had been fixed in front of louvred vents near the ridges of the foof of the large steel framed shed, possibly for blackout purposes. The building was of incombustible construction except for these boards, the louvres and roof light frames, and the purlins. In one bay of the building fire had occurred in the roof, and for the whole length of the bay, approximately 350 ft., the boards, the louvres and the window frames had been completely destroyed. The fire had spread down in a few places to burn portions of the purlins. There was no other trace of fire in the building, and no trace of any material within the building which might have started a fire. As in all these examples, there was no fired building within a considerable distance. It seems that the initiation of this fire was more likely due to primary radiation than to any other cause, but only one of 10 or 12 identical bays exposed to similar risk was fired: the phenomenon, like many fire phenomena, is one having a certain probability only.

The evidence afforded by the fires in reinforced-concrete framed buildings, also supported the view that many of them were due to primary causes.

Thus there were fires in the upper storeys of reinforced-concrete buildings whose basements screened from radiation had not been fired. Isolated fires occurred on different floors of the same reinforced concrete buildings, with no connecting fires on the stairs, as in Photograph No. 8; these fires presumably broke out simultaneously. There were fires on floors of R.C. buildings where there were windows exposed to heat radiation, with no fires on floors without exposed windows. There was absence of fires in buildings whose windows were masked by shutters, although there were fires throughout the surrounding area. In each case, blast blew the shutters open, so that fire-spread from adjoining buildings was possible; but of course radiation was over before the blast arrived. Striking examples of this at Hiroshima are: Building No. 85 at3500 ft. and Building No. 122 at 6300 ft. from G.Z/ Somewhat similar are Building No. 86 at 2400 ft. from G.Z., and an unnumbered three storey house of modern design in reinforced concrete with pre cast hollow block panel walls and timber floors, situated 4300 ft. from G.Z. on bearing N 76°.

No direct evidence was obtained of primary fires initiated by other materials than timber, but such materials would leave little trace and, in the light 4.2.8 must be presumed to be fired at least as frequently.

We Conclude that the risk of primary fire to unscreened industrial buildings is appreciable up to distances in excess of 5000 ft. from G.Z.

4.3.2. Convected Heat - No evidence could be found of primary fires caused by convection only. In the nature of things, however, it is difficult to visualisehhow this cause could have been isolated, or that it could be important in the presence of such intense radiated heat.

4.3.3. Secondary Fire - Electrical wiring everywhere was primitive, and electrical faults cannot be excluded as a cause of fire. The widespread damage to electrical substations would of course have caused the circuit breakers to function immediately, but "immediately" is not necessarily sooner than the sparking or heating necessary to start a small fire. Similarly, some fires will have been begun at gas leaks, overturned braziers (common in industrial as well as domestic buildings), and other secondary sources. It was not important to press this part of the ehquiry, since the danger of secondary fire always exists in large scale bombing. One isolated fire in a cleaning room at the hospital in Nagasaki was, however, fairly definitely established to be of secondary origin.

4.3.4. Fire Spread - There is no doubt that fire spread did occur in both cities; but more striking is the evidence for vast numbers of separate points of fire which made fire fighting hopeless from the outset among such highly combustible buildings. In fire resistant buildings, particularly in the industrial buildings at Nagasaki, the erratic incidence of fire in neighboring units was marked.

4.3.5. Nature of Fires - In summary, both primary and secondary fires must be regarded as active dangers from atómic bombs. Indeed, whether radiated heat is an important cause of fire or not, it is clear that the high temperatures produced by it create conditions exceptionally favourable to the emergence and continuance of serious fires, however caused. For example, rubble from demolished houses beyond the fire zone examined at Hiroshima would rarely have supported fire at ordinary temperature, yet it must have been rubble in this state which burned there for days, presumably as a result of the initial drying and scorching effect of the bomb. Sharp surface burning of trees and other timbers on the exposed side pointed to the same supporting effect. Finally, the general conditions of disorganisation produced by the bomb, and the multitude of individual incidents created by it must be foreseen: for they complicate the problem of fire fighting beyond recognition.

Combustible materials in fire resistant buildings were burnt with unusual completeness; the same is true of heavy timber sections in buildings employing timber framing. This does not necessarily point to very fierce fires, but may be the result of the long duration of fires of medium intensity which, it must be remembered, were allowed to burn virtually unchecked. Fuel for such fires was provided by the large amount of wooden material which the Japanese intruduce into buildings which would otherwise have been virtually fireproof. For example, the hospital at Nagasaki, between 2000ft. and 3000 ft. from G.Z., resisted the bomb exceptionally well; yet these fine concrete buildings were at once rendered useless, and nearly half the occupants killed, because the accumulation of heavy ceilings, wooden floors and other fittings with which they were filled burned uncontrollably. It is a very plain lesson that a fireproof building should not be converted into a major fire risk by ill chosen furnishings.

4.4 RADIO-ACTIVITY -

Three effects will be discussed here: in their natural order they are:-

1. Neutrons and gamma rays and other penetrating radiation
P produced as part of the total spectrum of energy, liberated by the fission process:

2. Radio-active primary products resulting from the fission: and

3. Induced radio-activity caused by interaction of neutrons with matter:

In what follows no attempt has been made to distinguish the effects produced by neutrons from those of gamma rays, as in character, both are highly penetrating and produce much the same effects as human beings with this exception that while neutrons produce by interaction with matter, induced radio-activity, none such occurs with gamma rays. That neutrons reacted thus, is evident from the work of the Japanese scientists who found the phosphorus in the human bones to be radio-active. Thus the neutrons appear hours after the explosion at Hiroshima in the westerly suburbs, down wind. In turn, this shower may have been the result of ionization produced by gamma rays.

4.4.2. Primary Fission Products - We have remarked the presence of these products, which must always be expected to be more important than induced radio activity. With bombs burst at lower heights, the ground, particularly rough ground, would contain markedly greater amounts of these products, in quantities which might be dangerous for days or longer.

4.4.3. Effects of Gamma Rays - Of these effects, overwhelmingly important is that on human beings.

4.4.3.1. Clinical Effects - The term gamma ray is used here in a general sense to include all penetrating radiations and neutrons that caused injury. It is possible that other types of radiation contributed to the injurious effects, but no attempt has been made to distinguish them. No mass irradiation of this sort has ever been seen before so that the results are of very great interest and importance. The effects of the gamma rays seen here do not differ markedly from the known effects of X-rays.

In general the gamma rays were very penetrating and the skin, which is relatively resistant, showed no effects. There were no skin lesions which could be directly attributed to the gamma rays.

Since the effects of X-rays may be unfamiliar to readers it is probably best to describe the typical results of irradiation with gamma rays before going on to discuss the effects of shielding,

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etc. This description, taken from Colonel Solandt's notes, is based on a hasty perusal of clinical records and is broadly correct. Anyone interested in a more detailed and documented description should see the complete medical report by the Joint Commission when it is ready.

Those who were fully exposed to the gamma rays but protected from flash burns and secondary injury showed no immediate ill effects. The most severely irradiated may have shown some nausea and vomiting and fever within the first 24 hours. Some Japanese suggest that a few cases died within 24 hours from irradiation but this is doubtful. The effects were so small that the Japanese were in doubt whether it was an atomic bomb until the news came to them by radio.

Following the fever and vomiting, bloody diarrhoea set in, most frequently in the second week, malaise and anorexia were marked at this stage. Epilation (loss of hair) appeared after the first week.

In the severe cases the clinical picture became dominated by the manifestations of deficient blood formation. It was apparent that the gamma rays had virtually killed the entire bone marrow in these cases. The cessation of red blood cell formation led to pupuric manifestations of all kinds. Petachiae (small haemorrhages in the skin), ecchymoses (larger haemorrhages under the skin), and retinal haemorrhages were common. Bleeding into the intestines and the kidneys was also seen. The cessation of white blood cell formation led to a leukopenia which was of considerable diagnostic value

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in the mild cases. In severe cases the leukopenia led to lowered resistance to infection which was followed in many cases by spreading infections in the mouth (agranulocytic angine with gangrene of the lips, tongue and occasionally of the pharynx). Death in these cases was due to a combination of the effects of anaemia, haemorrhages and infection. Deaths began about a week after exposure, reached a peak in about three weeks and had practically ceased by 6 to 8 weeks.

In the less severe cases diagnosis is rather difficult. Many cases showed epilation after 2 to 4 weeks. Others showed only purpuric manifestations (petechiae or retinal haemorrhages) or leukopenia. Diarrhoea, vomiting, malaise and anorexia were so common at the time as to be of little diagnostic value. The medical team have not quite decided upon the final criteria for a diagnosis of 'radiation sickness' in these milder cases. Some of the figures quoted below may be changed by a change in these criteria.

4.4.3.2. Radius of Effect of Gamma Rays - No exact figures are available, but there are a few incidents which give a fairly good guide to the radius of effect of the gamma rays. Two groups of workers from Otaki village were working in the open but screened by wooden buildings at 3600 ft. from the centre. The groups totalled 198, of whom six were killed immediately by debris. Of the remaining 192 no fewer than 95 subsequently died from the effects of radiation. Since the buildings gave these men some screening it seems safe to say that people in the open had a 50% chance of surviving the effects of radiation at some distance about 4000 ft. There is little doubt that the gamma rays killed nearly everyone who was fully exposed to them and protected from other forms of death at all ranges up to about 2500 to 3000 ft.

The outer limit of effect from gamma rays is hard to define because of the difficulty in diagnosis. Undoubted cases of epilation were reported at 6-7000 ft. and some medical men felt that there was some evidence of radiation sickness as far as 10,000 feet.

4.4.3.3. Shielding from Gamma Rays - The gamma rays from the atomic bomb show considerable power of penetrating even very solid buildings. This power of penetration is of the greatest importance since it necessarily alters the whole basis of personal protection against bombing. The medical section of the Joint Commission have devoted a great deal of time to getting exact data concerning the shielding effect of various types of buildings. These data are not yet complete and cannot be presented here but anyone interested in the subject should see the final report of the Medical Section. However, some qualitative statements can be made concerning the degree of shielding afforded by different types of buildings. Clothing and even fairly substantial wooden houses give no protection that can be detected by the rather crude observations that could be made. Evidence of protection against the gamma rays was seen only in the more substantial reinforced concrete buildings, where people were screened by several floors.

A few examples from Hiroshima will suffice to illustrate these shielding effects. Bankers Club - Building No. 11- This is an unusually strong three-story reinforced concrete building. There was no damage to the main structure except slight downward distortion of the roof panels even though the building is only 700 feet from G.Z. 23 people are definitely known to have been in the building when the bomb went off, though there may have been more. None of these was killed immediately. 20 had secondary injuries of some kind and 17 had burns. (It is not known whether these were flash or flame burns - probably flame). Most of these walked to the Red Cross Hospital for treatment. Of the 23 people, 21 died between the 12th and 23rd of August - probably all from the effects of gamma rays. Two survivors who are known to be alive and well were in the telephone room on the ground floor where they were shielded by all the floors in the building and possibly by adjacent structures. Since each floor contained the equivalent of at least 6" of concrete, some deaths must have been caused by gamma rays through 18 inches of concrete. (Each floor consisted of 2½ inches of cinders, 5¼ inches of concrete, 1¼ inches of plaster - in addition the roof had 3/4 inch of tile). <u>Chugoku Electric Building - Building No. 27 -</u> This is a large five-story reinforced concrete building situated 2100 feet from G.Z. A detailed study is being made of the distribution of casualties in relation to shielding. In general it may be said that there were casualties due to gamma rays on all floors on the side toward the bomb. On those parts of the floors that were fully shielded by the upper stories there were no gamma ray casualties in the basement and on the first and second floors, there were a few on the third floor and there were many on the fourth and fifth floors.

In the City Hall which is at about 5000 feet there were probably no casualties due to gamma rays. Only six possible mild cases of radiation sickness were described.

In the Communications Building of Chugoku Army Headquarters there were no casualties due to gamma rays (and, in fact only minor secondary injuries due to flying debris). This is a partly underground concrete shelter situated 2500 feet from the centre. The people in it (at least 26) were protected by about 3 feet of earth and 12 inches of concrete.

There were many examples of the penetration of buildings, etc. by gamma rays. In one case seen at Nagasaki a woman who was well inside the mouth of a cave which faced away from the bomb at a distance of 2600 ft. from G.Z. received an epilating dose of radiation through the earth over the mouth of the cave.

4.4.3.4. Effect of Gamma Rays on Reproduction -

A full investigation of this subject is being made by the Joint Commission and will be reported upon later. A very brief outline of the findings to date are:-

All pregnant women who survived within 3000 feet of the bomb have had miscarriages. These have been at all stages of pregnancy from 2 to 10 months. All those pregnant women who were from 3000 to 6500 feet from the bomb have either had miscarriages or have had premature infants that died very soon. In the ranges from 6500 to 10,000 feet about 1/3 of pregnant women have given birth to apparently normal children. Two months after the bomb the incidence of miscarriages, abortions and premature births was 27% compared to a normal 6%.

There is no doubt that much amenorrhoea has been caused by the gamma rays, but it is too early to decide the incidence and whether it will be permanent or not. Amenorrhoea had become so common in Japan, presumably as a result of poor diet, overwork, worry, etc., that a distinct syndrome called 'war amenorrhoea' was recognized. This greatly complicates the assessment of amenorrhoea attributed to the bomb.

In Hiroshima the Japanese, under American guidance, have done many sperm counts on both exposed and control cases. It appears that in cases exposed at under 4000 feet there is a considerable incidence of very low sperm counts or complete aspermia.

The final effects of this mass irradiation on human reproduction will not be clear for some years. Plans are being made to pursue the study to completion.

There were no obvious effects on plants. The Japanese commented in an early report on seeing new sprouts and leaves immediately under the bomb within less than a week. Delayed effects are being watched for. (See Photo No. 20).

5. CASUALTIES

5.1. SECONDARY CAUSES - The two causes of casualties which are peculiar to the atomic bomb have been discussed in section 4.2.9. and 4.4.3. As with most bombs, however, a high proportion of casualties, probably the bulk (except insofar as these were killed as it were several times over, by each casualty producing agent separately) died from secondary injuries.

The secondary injuries caused by the atomic bomb may be divided into mechanical injuries and burns. The mechanical injuries resulted mainly from people being struck by falling buildings. There appear to have been comparatively few cases of people being thrown against buildings. A general survey of clinical records gave the impression that these injuries accounted for a very considerable proportion of the casualties, but it is impossible to determine what that percentage was. It also seems likely that there were fewer cases with arms or legs violently removed by flying debris or fragments, since there were no people near enough to the bombs to encounter the high velocity missiles required to do this sort of damage. Although the Japanese house (see P. 21 and Plate 1) appears a light wooden structure it must not be depised as a lethal weapon. It has heavy roof timbers and heavy roof tiling, and these will partly account for the high incidence of secondary casualties. In addition, many of the reinforced concrete buildings, notably the hospital buildings in Nagasaki, contained a great amount of detachable material which could form secondary missiles. In these buildings there was a false lath and plaster ceiling hung on comparatively heavy timbers below the concrete ceiling. There was a wooden floor on wooden beams raised about 12 inches above the concrete, and plaster on battens and laths inside the concrete walls. Although the bomb caused no serious structural damage to these buildings many of the inmates were killed, seriously injured or trapped by the masses of debris brought down by the explosion. Many more were burned in fires that followed in most of the buildings.

The production of flame-burns by the fires that followed the burning required no explanation. They do not differ from the casualties due to fires in an incendiary raid. It is probable that many people were burned because the fires started simultaneously in many places while they were trapped under or hemmed in by debris.

What information is available indicates that secondary injuries did occur at distances up to 10,000 feet from the bomb, but that they were not common at this distance. Beyond 7000 feet the incidence of secondary mechanical injuries appears to fall off more rapidly than the incidence of flash burns and of secondary (flame) burns but much less rapidly than the incidence of gamma ray effects.

As is usual, there were some sensational stories of injuries produced by the over-pressure in the shock wave. For example, at Nagasaki several survivors reported that large numbers of bodies had their abdominal walls ruptured and their intestines protruding. One observer stated that the point of rupture was always on the same side although she could not remember which. Bodies were also said to have protruding eyes and tongues and to look as if they had been drowned. In at least two cases, survivors who had claimed to have seen hundreds or thousands of such bodies came down to one or two when they were actually taken to the spot and asked to point out where the bodies lay.

There is no reason to attribute such isolated cases to anything other than missiles.

Genuine effects of over pressure appear to have been scarce. For example, there were very few cases of ruptured ear drums. A Japanese survey of 106 cases at Hiroshima on August 11-12 showed only three cases with ruptured ear drums. In a later survey of 92 cases from Nagasaki at Omura Hospital in October, two cases were thought to have ruptured ear drums due to the bomb and three more such cases may have died. These findings are in keeping with the observed effects on buildings, which make it improbable that the maximum over pressure under the bomb was as high as two atmospheres.

5.2. RELATIVE IMPORTANCE OF DIFFERENT CASUALTY PRODUCING AGENTS -

No records exist giving any analysis of the cause of death in those who died immediately. Many opinions have been expressed and, in general, these agree that the immediate deaths were about half due to burns (flash and flame) and half to mechanical secondary injury. It is not possible to be more precise than this in the absence of further information.

There is a little more information concerning those who reached hospital. Of 155 Nagasaki patients that died in Omura Naval Hospital up to September 1st, 76% had burns and 24% had not. It is not known what was the cause of death in these cases but many certainly died of gamma rays and not of burns.

Analysis of the records of 1080 patients seen in hospital and in the outpatient clinics at Hiroshima gives the following results:

Distance	Cases Showing Definite Effect of Gamma Rays		Cases Showing no Gamma Ray Effects		Total Cases
	Cases	Percent	Cases	Percent	
0-½ km.	69	94	4	6	73
½-1 km.	323	95	16	5	339
1-1½	128	49	134	51	262
1½-2	68	24	210	76	278
2-2½	26	27	71	73	97
2½-3	12	39	19	61	31
					1,080

Data are being collected on a much larger group and in greater detail. Until these are vailable in the Joint Commission report it is impossible to say more than that a very high proportion of the injured showed effects of gamma irradiation and that this proportion was much higher near the bomb than further out.

An analysis was made of a few records of patients at Nagasaki to see how the various causes of injury varied with distance. The results of 381 cases were analyzed. There were 561 diagnoses on these cases since many cases suffered more than one type of injury. These cases were grouped into those within 0-1, 1-2 and 2-3 kilometres of G.Z. The diagnosis considered are given in the following Table. The figures in the table are the percentage of cases at each distance to which the particular diagnosis was given. The percentages total more than 100 because many patients had several diagnosis.

% OF PATIENTS SUFFERING FROM

Distance	Total No. of Cases	Epilation	Radiation Sickness	Flash Burns	Flame Burns	Secondary Injuries
0-1 km.	116	28	39	22	9	62
1-2 km.	215	36	41	52	9	50
2-3 km.	50	12	16	44	18	26

The low incidence of all diagnosis except secondary injuries within the first kilometre is probably due to the fact that only those who were very well protected survived in this area. These figures suggest that the incidence of gamma ray effects falls off more rapidly beyond 2 km. than does the indidence of flash burns. Secondary injuries fall off at an intermediate rate. The high incidence of flame burns at the greater distance may be due merely to the fact that the other casuses of injury have fallen off more rapidly than has this cause. In considering this table it is important to recall that the figures are not percentages of the population in each zone but merely percentages of the group of patients admitted from that zone. They give no idea of the total casualty production in each zone but merely show the relative importance there of each casualty producing agent among these patients.

5.3. NUMERICAL ESTIMATES -

5.3.1. Casualties in Hiroshima - No reliable figures are available of the casualties in Hiroshima. The official figures given by the Prefectural police office as of August 25th were:-

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Dead	47,185
Missing	17,425
	64,610
Injured	64,670

It is stated that the wounded who later died are listed only as injured.

Other estimates agree as to the number of immediate deaths but place the total casualties much higher. A typical estimate is that given by the Vice-Director of the Red Cross Hospital. He thinks that about 70,000 were killed at once, fifty to sixty thousand died in the next month and that only about 6000 of the population were completely uninjured.

The figures for dead probably include only those bodies that were found and identified. It is believed that the "missing" group is made up of bodies that were found but not identified and some notified as missing. Most of the Japanese were agreed that a good many bodies were never counted or identified.

The figures for injured are probably much too low. The hospitals were overworked and kept no adequate records. Many of the wounded went to distant hospitals (many even as far as Kobe) and many more did not go to hospital at all.

Casualties in School Children in Hiroshima -

It is obvious that gross casualty figures of the kind quoted are of no value in studying the lethality of the bomb at various

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distances. The only way of approaching this subject in retrospect seemed to be to try to trace the fate of each individual in some suitable group. It was found that there were fairly good records of the whereabouts of the school children and of their fate. The Medical Section of the Joint Commission therefore made an effort to collect complete data concerning these children and also of some industrial groups. None of these data have been completely collected and analysed yet. A part of the data on the school children is presented to indicate roughtly what may be expected from the complete data.

These children were organized into groups of various sizes and were scattered throughout the city doing a variety of war jobs. Very few of them were actually in school when the bomb fell. It was hoped that they are a fairly representative sample as far as proportion in the open, in various types of buildings, distance from the bomb, etc., are concerned. Any sampling bias is ignored here but will be investigated by the Joint Commission. The consolidated results for the many groups are:-

Distance from Centre	Total	Dead	Missing Unknown	Wounded Severe	Wounded Slight	Untraced Disconnected	Healthy
0-1 km.	3340	2479	289	35	0	166	371
1-1.5	4683	693	481	240	0	1643	1626
1.5-2	1260	227	22	168	0	343	500
2-2.5	5121	96	14	1123	0	832	3056
2.5-3	2314	11	0	37	0	0	2266

Missing (unknown is the word used by the Japanese) means that the child's parents did not know what had become of it.

Untraced (disconnected) means that it was not possible to get in touch with anyone in the family.

The most logical treatment of this data seems to be to assume that all those that are missing were killed and that the 'disconnected' suffered the same fate as the remainder at their distance, i.e., subtract them from the total. This gives the following results:-

Distance	Total	Killed	Percentage Mortality
0-1 km.	3174	2765	87
1-1.5	3040	1174	37
1.5-2	917	249	27
2-2.5	4289	110	2.6
2.5-3	2314	11	0.48

The Census Office was asked to divide the population of the town into small annuli one kilometre wide about the point where the bomb exploded. They make two attempts at this with somewhat similar results. The figures given to the Medical Section were:-

Distance	Population
0-1 km.	35,000
1-2 km	115,000
2-3 km.	79,000

Using these figures and the mortalities given it is easy to calculate the total casualties to be expected on the basis of this sample.

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Distance	Total cases less untraced	Dead plus missing	Percent Killed	Population	Number of Casualties
0-1	3174	2768	87	35,000	30,000
1-2	3957	1423	36	115,000	41,000
2-3	6603	121	1.8	79,000	1,000
				Total:	72,000

The highest and lowest possible values for the total casualties estimated from this sample can also be calculated. The highest figure is obtained if it is assumed that all those not reported healthy have now died. This gives a figure of 127,000 killed for the whole city. The lowest figure is given by assuming that all but the known dead survived. This gives total casualties of 44,000.

From all this evidence it is only possible to assume that the total killed in Hiroshima by the bomb was certainly not less than 60,000 and probably not more than 120,000 with the most likely figure between seventy and ninety thousand. It is not possible to estimate the injured with any useful degree of accuracy but they must have been at least as numerous as the dead. Thus of the 320,000 people in Hiroshima probably one quarter or more were killed and one third or more injured.

5.3.2. Casualties in Nagasaki - The official Japanese casualty figures for Nagasaki which were prepared for the Civil Defense Section of U.S.S.B.S. are probably the best available figures. They are to November 6th. They are:-

Dead	25,761
Injured	30,460
Missing	1,927

Homeless Families 21,174

Homeless Individuals 89,780

However, as before the figure for deaths is the number of vertified deaths obtained from the Governor of the Prefecture - actual deaths are much higher.

The figures for injured is for those actually hospitalized in Nagasaki; it is estimated that there were 25,000 more hospitalized outside.

It is usually concluded in medical circules that there were approximately 40,000 killed and at least 60,000 injured by the bomb in Nagasaki.

In order to test the percentage mortality obtained from the data on school children at Hiroshima, they were applied to Nagasaki by the following procedure. Figures were obtained for the pre-raid population of the 24 consolidated block associations of Nagasaki. The built-up areas of these 24 units were measured on a map, and their population distributed through the thousand foot annuli which they occupied in the ratio of the occupied areas, a lower index being given to areas known to have been thinly populated. In this way, an estimate of the distribution of population in thousand foot rings was obtained. A curve was fitted to the histogram of the data on the Hiroshima school children, and a subsidiary histogram constructed by thousand foot intervals. (These graphs are reproduced on a linear scale, but were, of course, calculated with weights proportional to annular areas). The following table was then obtained:-

Annulus	Percent Mortality	Pre-raid Population	Expected Killed
0 - 1,000 ft.	93 %	6,440	6,000
1,000 - 2,000 ft.	92 %	12,810	11,800
2,000 - 3,000 ft.	86 %	14,095	12,150
3,000 - 4,000 ft.	69 %	6,725	4,640
4,000 - 5,000 ft.	49 %	5,760	2,820
5,000 - 6,000 ft.	31.5 %	3,590	1,130
6,000 - 7,000 ft.	12.5 %	6,485	810
7,000 - 8000 ft.	1.3%	7,415	97
8,000 - 9,000 ft.	0.5 %	10,690	54
9,000 -10,000 ft.	0 %		

Expected killed in Nagasaki 39,500 -

It will be observed that the agreement with a figure of 40,000 killed widely accepted by the medical authorities is striking. In fact, we believe this estimate to be high, and prefer a figure of 34,000 dead which we have calculated from samples of known pre- and post-raid population and population movements in Nagasaki. This would suggest that the Hiroshima school children may have included a disproportionate number in the open. The general fit, however, is so satisfactory for example in a number of individual block associations at Nagasaki where it could be tested that these casualties reproduced in the

Graph, Fig. 2, and listed by thousand foot circles in the above table, undoubtedly give a valuable first approximation.

5.3.3. Standarized Killed Rate - It will be seen from the Table that, in round figures a man placed at random a mile from G.Z. stands only a little better than an even chance of escaping death. The standardized killed rate calculated from these figures is 70,000. Even if we take this estimate to be high, and if we make some allowance for the smaller vulnerability of people in British or continental houses, there is little doubt that the standardized killed rate of one atomic bomb, air burst as in Japan and of similar size, exceeds 50,000. This standardized killed rate is the expected number of killed in an area in which the density of population is uniform and 44 per acre - roughly the average density in central London. We have therefore to face the fact that an atomic bomb on central London must be expected to produce more than 50,000 dead.

This is probably the most important figure which this Report contains. It compares with a standardized killed rate (for a population half in the open and half in British houses) of about 35 per ton of explosive charge in ordinary HE bombs, and with a maximum of ten dead per acre in the heaviest incendiary raids on the densely populated areas of Hamburg and Tokyo. It is clear that the most serious danger presented by the atomic bomb is in producing casualties. The problem of protection against gamma ray casualties in particular is exceptionally grave and difficult.

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6. CONCLUSIONS AND APPLICATIONS

6.1. APPLICATIONS UNDER THE CONDITIONS OBSERVED -

We have given estimates of the average distance to which serious damage occurred in Japan to reinforced concrete buildings, factory sheds, Japanese houses, etc. From these in turn we have estimated the distances at which serious damage may be expected to continental buildings ($13\frac{1}{2}$" brickwork) and to normal British houses (9" brickwork). Confining ourselves in these conclusions to applications to Great Britain, we can summarize our relevant estimates in the following round figures:

Demolition or damage necessitating demolition: average radius 1 mile.

Houses rendered uninhabitable and requiring a considerable amount of repair: average radius $1\frac{1}{2}$ miles.

Houses temporarily uninhabitable and requiring lesser repair: average radius 2 to $2\frac{1}{2}$ miles.

We shall consider an average British urban area with a housing density of about 15 per acre, and a population density of about 45 per acre. In such an area, then, the number of houses demolished or requiring demolition as the result of the detonation of a single atomic bomb in the conditions which we studied would be approximately 30,000. The number of houses requiring considerable repair would be approximately

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35,000; and the number of houses temporarily uninhabitable and requiring first aid repairs would be of the order of 50,000 to 100,000. Thus a total of roughly 400,000 people might be rendered temporarily homeless, of whom about one half only could return to their houses after lesser repairs. Not all the remaining 200,000 would consitute a re-housing problem; unhappily, about 50,000 of them would be dead or would die within three to six weeks, and probably as many more would require extended hospital treatment. Thus the number of non-casualties to be re-houses, either permanently or for the months required to carry out major repairs, would be approximately 100,000.

This picture somewhat over-estimates the total effect, because few British urban areas are in fact as dense as this over a circle of five miles diameter, upon which these estimates are based. Nevertheless, they make vivid the scale of the disaster; in particular, they will be appropriate to an average incident in the larger British cities, such as London, Liverpool, Manchester, and Birmingham.

As our observations on factory sheds show (see section 3.2.3.), the distances at which normal factory structures would be effected are roughly comparable. The scale of the immediate industrial loss is thus of the same order. However, provided fire precautions are adequate and the machines are not left to weather, the final industrial loss can be considerably reduced; section 3.2.9. points out that it is these ancillary causes which were responsible in Japan for the greater part of the damage to machine tools.

It has long been known, from the experience of raiding in Britain, that framed buildings are much more resistant to blast than are buildings with load bearing walls (the normal British and Continental design). Our observations at Hiroshima and Nagasaki fully confirm this finding. We would expect steel framed and reinforced concrete buildings to suffer partial collapse on an average within a radius of less than half a mile. (See section 3.2.1) Casualties in such buildings are usually the result of structural collapse, falling ceilings and partitions, flying glass, etc. These causes should be minimized, and in particular the high missile and fire risk created by excessive use of wooden detail in the building, to which we have drawn attention at the hospital buildings in Nagasaki, should be avoided. Even so, such buildings cannot afford complete protection without unduly heavy and costly construction, and in particular remain subject to gamma ray effects (see section 4.4.3.3.). But they afford far greater protection than other types of construction, and should be advocated for all public and semi-public buildings. As the experience of such buildings in Hiroshima shows, their lower floors could be converted into shelters which could readily be made proof even against gamma rays.

6.2. LOWER BURSTS -

The effect of lowering the height of burst is compounded of a number of factors, no one of which is accessible to precise calculation. Among these factors are:

6.2.1. Direct Blast Effects - i.e., increase in blast effect as a result simply of the greater proximity of the bomb. It must be remembered that in Japan, the nearest building to either bomb was approximately 2000 ft., that is almost half a mile distant. Thus damage close to G.Z. could plainly be made more severe by lowering the height of burst. In general, this would have little advantage, since in this region the effects were already sufficiently destructive. It might, however, be employed to increase the damage to the most resistant buildings, such as reinforced concrete or steel framed buildings, aginast a target rich in those. At distances in excess of a mile, this effect would be inconsiderable.

The increase in the direct blast effect may be most serious against massive structures such as bridges and viaducts and against public services. Published pictures show that the New Mexico experimental burst, at a height of 100 ft., caused a depression of some feet up to a radius of about 250 feet, and of some inches up to perhaps 600 feet. This would suffice to cause serious damage to underground cables, gas mains, and water pipes, certainly over the central area of depression. Damage to bridges, viaducts, etc. would depend upon the type, heavy masonry structures would be little affected structurally beyond a few hundred feet, but plate girders, presenting a considerable lateral area to the blast wave, would be more vulnerable than at Nagasaki, i.e., some bridges might be expected to fail at distances of ½ mile or more.

6.2.2. Reflected Blast Effect - i.e., Changes in blast effect as the result of ground reflection. It is known that the total area of damage, to a desired severity, can be increased by raising the point of detonation of a bomb to some calculable distance above ground level. This is a subject on which much research is in progress, and results are by no means final. We have, however, remarked that the bursts in Japan appear to have been too high for the optimum effect. Thus, with bombs of this size, total damage may increase as the height of burst is lowered to about 1000 feet. Thereafter, overall damage would probably begin to fall off again towards its ground level value, which might be somewhat lower than that observed in Japan. The effect, however, is not likely to be very large; it is doubtful whether, even at optimum height, the distances which we have estimated could be increased by as much as 20%. Any increase is likely to show its greatest effect in the area of minor damage.

6.2.3. Radiation Effect - i.e., Changes in the distribution of radiation effects. As the height of burst is lowered, the area over which radiation, of any kind, reaches a given intensity is increased by an amount proportional to the difference of the squares of heights of burst. It can, however, readily be shown that, with normal street widths and a fully built-up area, this increase lies wholly in a zone screened by houses, and that meanwhile screening in the inner circle increases. Therefore, where such screening is effective - for example, against flash burn - casualties would be reduced. Where screening is less effective - for example, against gamma rays - the overall effect will probably be inconsiderable.

Against this screening effect must be set the increase in intensity of radiation at any point, which would result from lowering the height of burst, and which is inversely proportional to the square of its distance from A.Z. The effect of this, like the effect under (i) above, would be to increase mortality in the central region. Since percentage mortality there is already very high, the further contribution to the casualty rate could not be large.

6.2.4. Fission Products - i.e., increase in primary fission products in the ground. This is probably the most serious effect. Data on it should be obtained from the New Mexico trial. We can merely conjecture that, for a burst at or near ground level, primary fission products in dangerous quantities would be expected to be found at distances much in excess of a mile, and would remain dangerously radio-active certainly for a period of days. Streets and buildings would be less affected.

6.3. PENETRATING BOMBS -

Development in the size of atomic bombs, above a specific minimum, is to be expected. It is not clear how the effects would increase, since we have no empirical information on scale effects for such large explosions. Theoretical considerations make it fairly certain that the area of damage of any severity would not increase as rapidly as the weight of explosive material. Thus larger bombs would be less economical, in that the area of destruction from a given amount of material would not be so large as from the same material in bombs of the size we observed. Larger bombs, however, gain in compactness of the area of destruction, and the resulting disorganization would be correspondingly more serious.

A development which is presumably possible, and which must certainly be considered, is that of penetrating bombs. Figures have been given in 3.4 which suggest that the atomic bomb was equivalent to a bare charge of, at least 3000 tons of T.N.T., and possibly as much as 10,000 tons. It happens that 3000 tons is about the quantity of explosive which is thought to have detonated in the recent explosion of an underground ammunitions store near Burton-on-Trent. A survey of the damage there was carried out by the Research and Experiments Dept. of the Ministry of Home Security, and is available. The depth of the explosion was about 90 ft., and the crater produced was approximately 900 ft. in diameter. This agrees well with the estimates which we would make from our published material (see RE 2/4 data sheets 6A.2.). Basing ourselves on this material, then, and assuming that a bomb of the sizes used in Japan could be made to penetrate 100 ft. or more of clay, the expected diameter of the crater would lie between 800 and 1000 ft., and its depth would probably exceed 130 ft. A crater of this size would have contained initially nearly 2,000,000 tons of soil, which would be dispersed, some of it in very large lumps, over the surrounding area. The effect on public services would be extremly serious: for example, damage to the London Tubes would be serious at 1000 ft. from the point of explosion, and minor damage would extend to nearly double this distance. The radii of damage to other large underground pipes, such as sewers, are of the same order.

It is impossible to make estimates of the casualty effects, or to conjecture how much of the displaced crater material would carry dangerously radio-active primary fission products. While earth shock damage would be severe (at Burton-on-Trent chimney stacks were damaged up to nearly 6 miles), the total area of housing damage would not be expected to be as large as with a blast weapon. Damage to concrete buildings might be more severe than from the blast bomb. In general, then, while we would not regard the penetrating bomb as necessarily the preferred weapon, its use would enormously increase the disorganization of public services, the difficulties of rescue work, and all emergency organization.

6.4. OVERALL PICTURE -

The overall picture which emerges from this is sombre. Even ignoring changes in attack and developments of the weapon, the figures for housing damage given in 6.1 are very serious. And these figures are a measure only of the blast effect of the bomb. The point has been made in section 4.4. that a serious new problem is created by the risks of fire, primary and secondary, which the bomb produces. The minimization of this risk, by adequate city planning and fire resistant building, and the organization of an efficient fire serive on a large scale, are important tasks.

Finally, the point has been made in section 5.3. that the most serious aspect of the bomb is the number of casualties of all kinds which it produces. A standardized killed rate in excess of 50,000, only a 50% chance of survival at a mile from G.Z., are figures which speak for themselves. Measures of protection, particularly against penetrating gamma ray effects, measures of dispersal, and the organization of medical and rescue services, present a formidable problem.