Initial gamma radiation

4.6 Gamma rays can penetrate a considerable thickness of matter, e.g. the roof and walls of a building, but they are attenuated or weakened in doing so: they can be scattered back from the atoms of oxygen and nitrogen in the atmosphere, causing an additional hazard which can best be described as invisible "skyshine". Protection behind a heavy obstacle in the line of sight only will therefore not be so good as all-round cover under a heavy shield.

4.7 The biological effects of gamma radiation are outlined in Chapter II but there are several major differences between the effects of initial and residual radiation. In the first place, initial gamma rays are far more penetrating because they carry more energy* and they require a much thicker shield to give the same degree of protection. Secondly, while residual radiation from a fall-out area shines on an *exposed* person from all directions, the gamma flash comes mainly from one direction (apart from some scattered back from the atmosphere) and one part of the body may shield the other. On balance, residual radiation may be more injurious than gamma flash at the same *total dose*, i.e. the LD 50 or dose which would be lethal to 50 per cent. of those exposed might be significantly greater than 450r on exposure to flash gamma and significantly less than 450r in residual fall-out radiation (see also paragraphs 2.5 and 2.6).

Weapon power and range of effects

4.8 Table 4 shows the radial distances at which a 50 per cent. lethal dose of 450r (i.e. a fifty-fifty chance of survival) and a war-time emergency dose of 75r would be received by people exposed in the open to initial radiation from a ground burst or an air burst (the difference between these is swamped when the figures are rounded off to the nearest quarter of a mile).

TABLE 4

Radial distances (in miles) of initial gamma effects on people exposed in the open to a ground- or air-burst nuclear weapon

Weapon power	*20 KT*	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
50 per cent. survival (450r)	¾	1	1¼	1½	1¾	2	2¼
No appreciable risk of sickness (75r)	1	1¼	1½	1¾	2	2¼	2½

It will be noticed in comparing the two rows of figures for each weapon power that, because of absorption and attenuation in the air, the dose decreases much more rapidly with distance than would be predicted by the "inverse square" law (paragraph 1.31). The data† in the Table are adequate for most civil defence purposes. It will be

---

* The energy of gamma radiation is usually expressed in units of a million electron volts (Mev): the gamma ray released when a nitrogen atom captures a neutron may exceed 10 Mev: the average energy of initial gamma radiation is 4.5 Mev whereas that of residual radiation from fall-out is only about 0.7 Mev.

† These data are taken from more elaborate data in the series of curves on page 352 of the U.S. publication "The Effects of Nuclear Weapons" (see Preface) where similar curves for neutron and neutron plus gamma doses are shown on pages 366 and 372.

Skin burns

5.6 Skin burns can be of various degrees of severity from a mere reddening (first degree) or a more painful blistering (second degree) to a much more serious charring of the skin (third degree). It is obvious, too, that the duration of the heating may be as important as the total amount of heat in causing skin burns or igniting inflammable material since the temperature of a surface will not increase if its rate of dissipating heat is greater than the rate of heating. Hence, it is necessary to consider three important factors viz: the total amount of heat, the area on which it falls and the duration of application of this quantity of heat to the surface.

5.7 A convenient unit for expressing a quantity of heat is the calorie* (abbreviated to cal.). Heating effects on surfaces should be compared in terms of calories per unit area of surface, i.e. cals. per square centimetre.

5.8 Table 6 shows the ranges in miles at which people in the open would suffer various degrees of skin burn from ground-burst weapons of different power. Table 7 shows similar data for air-burst weapons.

TABLE 6

Range of heat effects on people exposed in the open: radii in miles for ground-burst weapons

Weapon power	*20 KT*	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
3rd degree burn charring of skin	⅞	1½	3½	4¾	6¼	9½	13
2nd degree burn blistering of skin	1	2	4	5½	7½	11	15
1st degree burn reddening of skin	1½	3	5½	8	11	15	21

TABLE 7

Range of heat effects on people exposed in the open: radii in miles from air-burst weapons

Weapon power	*20 KT*	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
3rd degree burn	1⅜	2½	6	8	11	16	22
2nd degree burn	1¾	3½	7	9	13	18	25
1st degree burn	2½	5	9	13	17	25	35

The fire situation

5.9 Table 8 shows the ranges (radii) of the main fire zones and the limits out to which isolated fires would occur from ground-burst weapons of different power. Table 9 shows similar data for air bursts. It will be noted that the ranges from an air-burst weapon are much greater than those from a ground-burst weapon: also that the main fire zone would be ring-shaped. Within the inner ring fires would be extinguished by the general destruction of the houses and buildings.

---

* 1 calorie is the heat required to raise the temperature of 1 gram of water 1°C. from 15° to 16°C.

TABLE 8

Possible fire situation: ground-burst weapon: ranges in miles

Weapon power	*20 KT*	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
Main fire zone	⅜ to 1	¾ to 2	1¼ to 3½	1½ to 5	2 to 6½	2¾ to 9	3½ to 12
Limit of isolated fires	1½	3	5	7	9	13	17

TABLE 9

Fire situation: air-burst weapon: ranges in miles

Weapon power	*20 KT*	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
Main fire zone	½ to 1⅝	⅞ to 3	1½ to 6	1¾ to 8	2¼ to 11	3¼ to 15	4–20
Limit of isolated fires	2	5	8	12	15	22	28

Thermal effects of weapons of different powers

5.10 A 10 MT weapon radiates 500 times as much heat as a 20 KT bomb. According to the "inverse square" law (paragraph 1.31) a 10 MT weapon should produce the same amount of heat as the 20 KT weapon at a distance 22 times greater (since $\sqrt{500}=22$ approx.). But the heat from the larger bomb is spread over a much longer period, 20 seconds compared with a 1½ second flash from the 20 KT bomb, so that more of the heat is dissipated or conducted away from the surface and it takes a total of 12 cals./sq. cm. (which is delivered at about 12 miles) to start fires from a 10 MT weapon compared with a total of only 5 cals./sq. cm. (which is delivered at 1 mile) from a 20 KT weapon. For this reason as well as for the reason indicated in paragraph 5.5, no simple scaling law can be given for the ranges of thermal effects from weapons of different powers.

Personal protection from thermal radiation

5.11 To gain protection from thermal radiation it is necessary to get out of the direct path of the rays from the fireball and any kind of shade will suffice. People caught in the open should dive behind any available cover. In this way serious burns may be avoided, particularly from the longer-lasting fireball. It is also important to get adequate cover from glass splinters and other debris (see paragraph 11.13).

5.12 The importance of keeping as much of the skin covered as possible is illustrated by the fact that the risk of death from burns depends on the proportion of the body surface which has been burned. If this is below 20 per cent., the chance of recovery with skilled medical attention is high except for very old people. Even with 50 per cent. of the body surface burned, young people have a 50 per cent. chance of recovery. Clothing offers some protection if it is loose fitting, and the lighter the colour the better. Outer garments of wool are better than cotton as wool melts but cotton inflames.

CHAPTER VI

Crater Formation and Ground Shock

Introduction

6.1 When a nuclear detonation takes place on or near the ground an appreciable amount of the energy is expended in making a crater and, at the same time, a shock wave is transmitted outwards through the ground.

6.2 The effect of a burst in the shallow water of an estuary or harbour will be similar to that of a ground burst except that the crater will be submerged, quantities of mud and water will be sucked up into the fireball and much water will be vaporised. A burst in deep water will cause a shock wave to be transmitted through the water at higher speeds and to greater distances than a blast wave in the air (see also paragraphs 1.19 and 1.20).

Crater formation

6.3 In a surface burst a considerable quantity of vaporised or pulverised material is sucked up by the ascending fireball and associated air currents. A still larger quantity is gouged out of the crater by the force of the explosion and is deposited around the crater to add to the " lip " formed by the ground which is squeezed up round the edges of the crater. The combined lip formed in this way has a width roughly equal to the radius of the crater and a height of about a quarter of the depth of the crater.

6.4 The dimensions of craters produced by weapons of different powers are shown in Table 10 for nuclear detonations on saturated clay: on dry soil or hard rock the craters are slightly deeper but less extensive. Appropriate conversion factors for bombs burst on dry soil and hard rock are given beneath Table 10. Scaling laws for crater dimensions and a formula for calculating the total volume of a crater are listed in Appendix 2, paragraph 2.

TABLE 10

Crater dimensions (in feet) for a ground burst in saturated clay*

Weapon power	*20 KT*	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
Radius of crater	300	510	850	1,100	1,360	1,700	2,200
Radius of crater lip	600	1,020	1,700	2,200	2,720	3,400	4,400
Depth of crater	40	55	80	100	120	150	170

* To get ranges (radii) in dry soil, divide the above values by 1.7.
To get depths in dry soil, divide the above values by 0.7.
To get ranges (radii) in hard rock, divide the values in the table by 2.
To get depths in hard rock, divide the values in the table by 0.9.

Ranges of damage to typical British houses and of road blockage

7.12 The various degrees of structural damage in built-up areas would in turn cause corresponding hindrance and obstruction to civil defence forces in vehicles and on foot. Table 11 shows the ranges of various categories of damage and street blockage for ground-burst weapons of different powers. It is expected that slight damage to typical British houses would occur when the static overpressure (pounds per square inch, abbreviated to p.s.i.) in the shock front was about 0.75 p.s.i.; at 1.5 p.s.i. the houses would need repairs to remain habitable and they would be irreparably damaged at about 6 p.s.i.

TABLE 11

Average ranges (radii) of blast damage to typical British houses and blockage of streets

Ground-burst nuclear weapons: ranges in miles

Weapon power	*20 KT*	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
11psi *Damage ring "A"* Houses totally destroyed, streets impassable	0–⅜	0–¾	0–1¼	0–1½	0–2	0–2¾	0–3½
6psi *Damage ring "B"* Houses irreparably damaged, streets blocked until cleared with mechanical aids	⅜–⅝	¾–1	1¼–1¾	1½–2¼	2–3	2¾–3¾	3½–5
1.5psi *Damage ring "C"* Houses severely to moderately damaged: progress in streets made difficult by debris	⅝–1⅝	1–2¾	1¾–4¾	2¼–6	3–7½	3¾–10	5–13
0.75ps *Damage ring "D"* Houses lightly damaged, streets open but some glass and tiles	1⅝–2½	2¾–4¼	4¾–7¼	6–9	7½–12	10–15½	13–20

Effects on bridges

7.13 As already noted, wind drag is the primary damaging mechanism against open girder bridges, though these bridges may also be lifted bodily and moved from their abutments as a result of blast reflection from the ground or water underneath them. Table 12 shows the expected ranges of damage to bridges from ground-burst bombs.

TABLE 12

Bridge damage from ground-burst nuclear weapons
(ranges in miles from ground zero)

Weapon power	*20 KT*	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
Steel truss type bridges— Collapse	½	1	1½	2	2½	3¼	4
50% reduction in capacity	¾	1¼	2¼	2¾	3½	4¾	6
No reduction in capacity	1	1½	2½	3¼	4	5½	7
Bridges, heavy masonry or concrete Collapse	¼	⅓	½	¾	1	1¼	1½
50% reduction in capacity	¼	½	1	1½	1¾	2½	3
No reduction in capacity	½	¾	1½	2	2½	3¼	4

Effects on human beings

7.14 Human beings run small risk of being killed outright if the static overpressure is below about 200 p.s.i. but ear drums may burst at 15 p.s.i., lung damage may start at 35 p.s.i. and serious internal injuries may be caused by pressures approaching 200 p.s.i. Glass fragments probably represent the blast hazard with the greatest range; it is expected that the outer limit of serious casualties from this cause among people in houses would be about 11 miles for a 10 MT bomb. For people in the open, the main risk (apart from debris and missiles) is being blown over by the blast wind. A person standing in the open would be blown over at a distance of about 9 miles from a 10 MT ground-burst bomb; he would be moved bodily if lying prone across the direction of blast at about 7 miles, and if lying prone in the direction of the blast, at about 4 miles.

Effects on vehicles

7.15 Cars and buses with their windows closed would be liable to be crushed by external blast pressure, but the more serious risk is that of being blown over by the drag forces arising from the blast wind. The estimated ranges of severe displacement of motor vehicles are given in Table 13.

TABLE 13

Motor vehicle damage from ground-burst nuclear weapons
(ranges in miles from ground zero)

Weapon power	*20 KT*	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
Severe displacement of motor vehicles at	¾	1¼	2¼	2¾	3½	4¾	6

Effects on public utility services

7.16 Except near the crater (see paragraph 6.6) the effect of a nuclear detonation on public utility services would probably be confined to damage above ground, e.g. to poles and pylons carrying overhead telephone and power lines. Damage to delicate equipment in the exchanges would cause disruption of the telephone service out to ranges corresponding to those for moderate damage to houses (see Table 11). Installations such as gas works and holders, water pumping stations, electricity generating stations and sub-stations would suffer structural damage or be damaged as a result of the collapse of buildings. In general, underground services such as water and gas mains would be undamaged unless very close to the crater, but the connections might be ruptured where the pipes enter buildings shaken or damaged by blast.

The debris problem

7.17 It will be seen from Table 11 that the problem of access would be a serious one in built-up areas. Movement of vehicular traffic might be seriously restricted or prevented over wide areas where fire fighting and rescue are required. Access routes should be sought which are more radial to the point of burst and therefore less likely to be blocked to the same degree and it should be remembered that wide streets or streets with front gardens or wide footpaths would not be blocked to the same extent. Parks, open spaces, railway embankments, wide roads, rivers, canals might all provide entry and exit routes for civil defence operations.

7.18 Trees are very vulnerable to long duration blast and in many cases fallen trees would block roads at a greater distance from ground zero than any other type of debris. The estimated distances for tree damage from ground-burst bombs are given in Table 14 (trees in leaf).

TABLE 14

Tree damage from ground-burst nuclear weapons (ranges in miles from ground zero)

Weapon power	*20 KT*	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
Trees							
90% blown down	1	1¾	3	3¾	4¾	6¼	8
30% blown down	1¼	2¼	3¾	4¾	6	7¾	10
Branch damage	1¾	3	5	6¼	8	10½	14

pattern. In comparing the fall-out patterns from weapons of different powers, it has been found that the areas within reference contours having the same dose-rate are approximately proportional to the fission yield of the weapon, e.g. the area enclosed by the 10 r.p.h. DR1 contour from a 1 MT fission explosion is 50 times that from a 20 KT explosion (see scaling laws in Appendix 2). While this relationship holds very roughly within a factor of two either way for downwind contour areas, the contamination pattern upwind and crosswind from ground zero is more complex and cannot be adequately described by such simple scaling laws. This is not unexpected as the upwind contaminated area will be a small fraction of the total fall-out pattern.

Downwind areas covered by fall-out

8.19 Table 15 shows the approximate areas covered by a series of dose-rate contours at the most convenient reference time of seven hours after surface bursts of weapons ranging from 20 KT to 10 MT in power. In some fall-out patterns the contours of lower intensity may be increased in area at the expense of the higher intensity contours or vice versa.

TABLE 15

Downwind contamination

Areas of contours at 7 hours after burst, assuming 100 per cent. fission yield

Reference contour dose-rate r.p.h. at 7 hours after burst (DR7's)	*Areas in square miles for weapon power*						
	20 KT	*100 KT*	*½ MT*	*1 MT*	*2 MT*	*5 MT*	*10 MT*
300	0.2	1.2	27	54	108	270	540
100	1.3	6.4	105	210	420	1,050	2,100
30	5	25	325	650	1,300	3,250	6,500
10	16	82	750	1,500	3,000	7,500	15,000
3	50	250	1,650	3,300	6,600	16,500	33,500
1	200	1,000	4,250	8,500	17,000	42,500	85,000

8.20 As indicated in paragraph 8.14 the fall-out pattern from surface bursts in some British weather conditions might be very irregular. For detonations of the same fission yield, however, each reference contour of the same dose-rate would enclose roughly the same area. The time from detonation to the first arrival of fall-out at any place would depend on its distance from the explosion, on the bomb power, on the sizes of the particles and on the pattern of the winds up to the cloud level. For megaton weapons the time from first arrival to the time when maximum dose-rate is reached at any point is about the same as the time from detonation to first arrival, and fall-out is generally complete in about five hours after the maximum dose-rate has been reached.

8.21 Table 15 shows that people in large areas of the United Kingdom would need substantial shelter from residual radiation and that they would have to remain under cover for some time. For example, the